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AN INVESTIGATION OF METHODS OF IMPROVING SUBSONIC PERFORMANCE OF A MANNED LIFTING ENTRY VEHICLE

by Bernard Spencer, Jr.

Langley Research Center

Langley Station, Hampton, Va.

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AN INVESTIGATION OF METHODS OF IMPROVING SUBSONIC PERFORMANCE OF A MANNED LIFTING ENTRY VEHICLE*

By Bernard Spencer, Jr.
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SUMMARY

An investigation has been made in the Langley high-speed 7- by 10-foot tunnel at a Mach number of 0.35 to examine various methods of improving the landing performance characteristics of blunted-base lifting-body configurations. The model selected for the study was the HL-10 configuration, considered representative of the aforementioned type of vehicle. Most of the modifications incorporated were made bearing in mind that little or no alteration of the pertinent entry-configuration design lines should be attempted.

In general, significant increases in the maximum untrimmed lift-drag ratio of the basic configuration were obtained as a result of reductions in base drag associated with the blunt-base vertical tails. This reduction in base drag was accomplished by either boattailing the aft sections of the tails to approximately a zero base thickness, or altering the section shapes to give the same result. These changes caused only minor effects on either the lift or the pitching-moment characteristics of the basic configuration. Further improvements in performance were obtained by use of splitter plates (flat-plate base extensions) located at various positions in the body base regions between the circular center section (considered an egress hatch area) and the outboard vertical tails. The largest improvements in performance resulted from a change in the body upper surface contour which reduced the volume near the region of the elevon controls and reduced the base area by approximately one-half.

INTRODUCTION

Manned lifting entry vehicles possessing the capability of conventional horizontal landings have been the subject of considerable research throughout the National Aeronautics and Space Administration. Several configurations which appear suitable for this type of mission requirement have been tested over a range of Mach numbers from low subsonic to hypersonic. (See refs. 1 to 10.) The desirability of providing some lift and lift-drag ratio at hypersonic speeds is apparent from range and maneuverability considerations (as

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noted in refs. 11 to 13). However, in order to alleviate some of the problems associated with reentry heating, vehicle design requirements result in compact-volume, highly swept, low-span configurations having blunted base areas. Each of these design characteristics is undesirable for low subsonic speeds because the low values of lift and lift-drag ratio generated result in marginal landing capabilities. The question arises, therefore, of how to improve the subsonic performance characteristics without resorting to the complexities of extendable wings or lifting surfaces.

The present investigation was initiated to examine various methods of improving the vehicle performance at low subsonic speeds without penalizing the salient configuration design points. The configuration selected for study is the vehicle of references 1 to 5, designated HL-10 (horizontal lander 10). The various changes which are presented should be applicable to any generalized hypersonic configuration similar in design to this type of lifting-body vehicle. The major portion of the investigation dealt with possible methods of reducing base area or alleviating base drag in areas which would be unaffected at reentry conditions or at hypersonic speeds. All tests were made at a Mach number of 0.35, corresponding to an average test Reynolds number based on the body length of 5.73×10^6. The angle of attack varied from approximately -5° to 23° at a sideslip angle of 0°.

SYMBOLS

All data are referred to the stability axis system, with all coefficients nondimensionalized with respect to the actual length, span, and projected plan-form area of the body. The reference center of moments was located at 53 percent of the body length aft of the nose, and at 1.25 percent of the body length below the body reference line. (See fig. 1(a).)

b	span, 19.68 in. (50.00 cm)
c	chord, in. (cm)
C_L	lift coefficient, $\frac{\text{Lift}}{qS}$
C_D	drag coefficient, $\frac{\text{Drag}}{qS}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qSl}$
l	body length, 30.54 in. (77.57 cm)
L/D	lift-drag ratio
q	dynamic pressure, lb/ft^2 (N/m^2)

S body planform area, 2.31 ft^2 (0.2145 m^2)

α angle of attack, deg

δ_s splitter plate deflection (referred to body reference line), positive when trailing edge down, deg

Subscripts:

l lower surface

min minimum condition

max maximum condition

u upper surface

MODEL

Model Component Designations

Design criteria for the HL-10 configuration and basic-body section details are presented in references 1 to 5 and 9 and 10. A drawing of the basic configuration of the present investigation is presented in figure 1(a). A photograph of the HL-10 configuration is presented in figure 2.

The body modifications are identified as follows (see fig. 1(b)):

B_0 original HL-10 body

B_1 large added volume to top of body

B_2 small added volume to top of body

B_3 reduced volume from top of original body

Modifications of the center-line vertical tail are identified as follows (see fig. 1(d)):

V_i1 basic HL-10 wedge tail (designated E_2, ref. 9)

V_i2 NACA 65-006 airfoil section

V_i3 basic HL-10 tail faired from approximately 25 percent chord to a near zero thickness at trailing edge

V_i4 basic HL-10 wedge tail with boattailed rudder

Modifications of the outboard vertical tail are identified as follows (see fig. 1(e)):

V_o0 basic HL-10 outboard tails (designated I_4, ref. 9)

V_o1 slab-sided, or flat-plate outboard tails

V_o2 cambered inner side of basic outboard tails

V_o3 cambered inner and outer sides of outboard tails

V_o0' basic HL-10 tail with boattailed outer surface

Body Modifications

Three body changes have been tested in which the body upper surface has been altered from the original B_o. In the first modification, the upper portion of the body volume was increased by filling in the base of the model and adhering to the top surface lateral contours where possible. (See fig. 1(b), body B_1.) The contours were formed by straight-line or ray extensions from body station 12.58 to the body trailing edge. The resultant base area, in the region between the outboard tails and the circular chamber, was approximately doubled. Body B_2 was formed by reducing body B_1 by half the added base height, as shown in figure 1(b). Body B_3 was obtained by lowering the upper surface contour from body station 12.58 to the trailing edge; this change resulted in a considerable reduction in base thickness. The major reduction in volume for body B_3 occurred in the region of the elevons, where the volume appears to be unusable.

Body Base Modifications

Various methods of reducing the body base drag by means of closing the base flow have been investigated. These methods include attaching splitter plates to the top, middle, and top and bottom of the body base; adding wedges to close the base entirely; and fairing the lower surface in the region of the original elevon. Details of each of these base modifications are presented in figure 1(c).

Vertical Tail Modifications

Modifications of the basic center-line vertical tail V_i1 are shown in figure 1(d). These alterations included: replacing the basic tail with the NACA 65-006 airfoil section having a closed base (designated V_i2); fairing the basic tail from approximately 25 percent chord to near zero thickness at the trailing edge (designated V_i3); and boattailing only the rudder section of the basic tail (designated V_i4). Modifications of the basic outboard vertical tails V_o0, as shown in figure 1(e), included: changing the tail sections to flat plates or slab sections (designated V_o1); cambering the basic inboard surfaces of the tails (designated V_o2); and cambering both the inboard and outboard surfaces of the tails (designated V_o3). The basic vertical tails V_o0 with only the outboard surfaces faired (designated V_o0') were also tested. The fairing started at approximately 25, 50, and 80 percent of streamwise tail chord. (See fig. 1(e).)

TEST AND CORRECTIONS

The present investigation was made in the Langley high-speed 7- by 10-foot tunnel at a Mach number of 0.35, corresponding to an average test Reynolds number based on body length of 5.73×10^6. The model was sting mounted, and forces and moments were measured by means of a six-component strain-gage balance. The angle of attack ranged from approximately -5° to 23° at a sideslip angle of 0°.

Jet-boundary and solid-blockage corrections, determined by the methods described in references 14 and 15, respectively, have been applied to the data. The angles of attack have been corrected for the effects of sting and balance bending under load.

All drag data of this investigation represent gross drag, and have not been corrected to a free-stream static condition in the blunted-base region.

PRESENTATION OF RESULTS

The results of this investigation are presented in the following figures:

DISCUSSION

A detailed study of various geometric alterations which may improve the performance characteristics of lifting body vehicles has been made on the HL-10 configuration, with results presented in figures 3 to 12. Inasmuch as the hypersonic reentry characteristics of the configuration are primarily dependent on the shape of the body lower surface and the outboard-tail outer surface, for most of the modifications examined in the present investigation either these shapes were not altered, or they were altered in such a way that the original shape could be restored with a movable flap.

The effects of changing the geometry of the center-line and outboard tails are presented in figures 3, 4, 6, and 7. Changing the center-line vertical tail from a wedged section to an NACA 65-006 airfoil (V_i2) (fig. 3) produces large reductions in $(C_D)_{min}$ and the drag throughout the angle-of-attack range investigated, with only minor effects on either the lift or the pitching-moment characteristics. Thus an increase in $(L/D)_{max}$ from approximately 3.9 to 4.4 results. This tail-geometry change appears feasible from reentry aerodynamic heating considerations, since the envisioned entry occurs at a high angle of attack and thus this center tail is well shielded. Approximately the same results are obtained with the basic center-line tail faired to a near zero base thickness from approximately 25 percent chord (V_i3, fig. 7). Similar but lower increases in performance are also obtained by boattailing only the rudder section of the basic center tail (compare V_i1 and V_i4 having V_o0' hinge line at 50 percent chord and body lower surface boattailed). This sharp rudder boattailing, however, may result in considerable reduction in rudder effectiveness because of separation induced by the wedge shape ahead of the sharply boattailed rudder.

The effects of changing the geometry of the outboard vertical tails are presented in figure 4. Although the effects of modifying the tail cross section on the overall aerodynamic characteristics are significant, the most notable gains in performance result from boattailing the outer surface of the original tail. This tail change also resulted in the least out-of-trim moment in the region of $(L/D)_{max}$. Therefore, less trim-drag penalty and less loss in $(L/D)_{max}$ due to trim may be expected. Some nonlinearities in the variation of C_m with C_L in the range of C_L from about 0.1 to 0.3 were noted for the tail V_o0' with the hinge line at 25-percent tail chord. The effects of outboard-tail hinge-line location for the outer edge boattailing are presented in figure 6 for configuration $B_oV_i2V_o0'$ having the bottom elevon surface boattailed. Some reduction in the value of $(L/D)_{max}$ occurs as the hinge line is shifted aft (maintaining constant base area), but less out-of-trim moment was also noted.

A comparison of the effects of vertical-tail changes in combination with the original body B_o with and without vortex generators and boattailed elevons is presented in figure 5. A comparison of the performance characteristics for the basic configuration $B_oV_i1V_o0$ and the modified configuration $B_oV_i2V_o0'$, having boattailed elevons on the lower surface and vortex generators, indicates that these modifications increased the value of $(L/D)_{max}$ from approximately 3.9 to 6.2, with a resultant reduction in the out-of-trim moment at $(L/D)_{max}$ from approximately -0.042 to -0.026.

Inasmuch as the largest portion of base area which may be altered occurs between the circular center section (considered an egress hatch area) and the outboard tails, several methods of base-drag reduction have been attempted, with results presented in figures 8 to 10. The addition of a wedge to this base region indicates the most notable gains in performance $\left((L/D)_{max} \approx 6.35,\right.$ fig. $\left.8\right)$, as might be expected, because the wedge closes the base region entirely. Deflection of the elevon region of the body with the wedges on for longitudinal trim, however, may be expected to induce separation earlier than with the wedges off, and nonlinearities in pitch due to the excessive angles the wedges make with the body reference line would result.

The addition of vortex generators to the body upper surface for the configuration $B_0V_i2V_o0'$ having wedges on further increased the maximum lift-drag ratio from $L/D \approx 6.35$ to $L/D \approx 6.8$ and improved the variation of C_m with C_L below $C_L = 0.50$. (See fig. 9.) The location of these generators (see fig. 1(a)) was selected after observing tuft studies of the model, and since the flow is critical to changes in Reynolds number, the improvements noted for these particular generators may be applicable only at low Reynolds numbers. However, vortex generators used on the full-scale vehicle may be beneficial if they are located in a position to alter the full-scale flow characteristics.

The longitudinal characteristics associated with the addition of splitter plates and vortex generators to the configuration having the bottom elevon surface boattailed are presented in figure 10. The addition of vortex generators and a splitter plate to the top of the base gives a value of $(L/D)_{max}$ of approximately 7.1. Increasing the boattail angle on the elevon bottom surface while keeping the upper surface fixed should produce trim at positive lift coefficients.

The effects of changing the body upper surface contour for the configuration having the airfoil-section center-line tail (V_i2) and the basic outboard tail boattailed from 25 percent chord (V_o0') are presented in figure 11. It is interesting to note that increasing the base area of bodies B_1 and B_2 (which results in less upper surface change in slope near the base region) results in large increases in minimum drag, but it also shows less out-of-trim moment at C_L corresponding to $(L/D)_{max}$ than the original body B_0. The largest increases in $(L/D)_{max}$, however, are noted for body B_3, for which the volume near the region of the elevon controls was reduced and the base area was reduced by approximately one-half. Body B_3 also shows the lowest value of minimum drag and the least out-of-trim moment at C_L corresponding to $(L/D)_{max}$. Body B_3 also has less change in upper surface slope in the region of the base than the original body B_0. The changes noted in the variation of C_m with C_L result primarily from changing the camber of the configuration.

The effects of elevon bottom-surface boattailing and various locations of the outboard-tail rudder hinge line in combination with the small body B_3 are presented in figure 12. Trimmed values of $(L/D)_{max}$ are greater than 6.0.

The configuration $B_3V_i2V_o0'$, having outboard-tail hinge-line location at 50 percent chord and a boattailed elevon, appears to be the most promising configuration investigated. A comparison made between this configuration (fig. 12) and the original body with the same modifications $B_oV_i2V_oO'$ (fig. 5) indicates that, whereas the values of $(L/D)_{max}$ are approximately the same, the configuration $B_oV_i2V_oO'$ is approximately $-0.025C_m$ out of trim, and, as previously noted, the configuration $B_3V_i2V_oO'$ is trimmed at $(L/D)_{max}$.

CONCLUDING REMARKS

An investigation has been made in the Langley high-speed 7- by 10-foot tunnel at a Mach number of 0.35 to examine various methods of improving the landing performance characteristics of blunted-base lifting-body configurations. The model selected for the study was the HL-10 configuration, considered representative of the aforementioned type of vehicle. Most of the modifications incorporated were made bearing in mind that little or no alteration of the pertinent entry-configuration design lines should be attempted.

In general, significant increases in the maximum untrimmed lift-drag ratio of the basic configuration were obtained as a result of reductions in base drag associated with the blunt-base vertical tails. This reduction in base drag was accomplished by either boattailing the aft sections of the tails to approximately a zero base thickness, or altering the section shapes to give the same result. These changes caused only minor effects on either the lift or the pitching-moment characteristics of the basic configuration. Further improvements in performance were obtained by use of splitter plates (flat-plate base extensions) located at various positions in the body base regions between the circular center section (considered an egress hatch area) and the outboard vertical tails. The largest improvements in performance resulted from a change in the body upper surface contour which reduced the volume near the region of the elevon controls and reduced the base area by approximately one-half.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., July 8, 1965.

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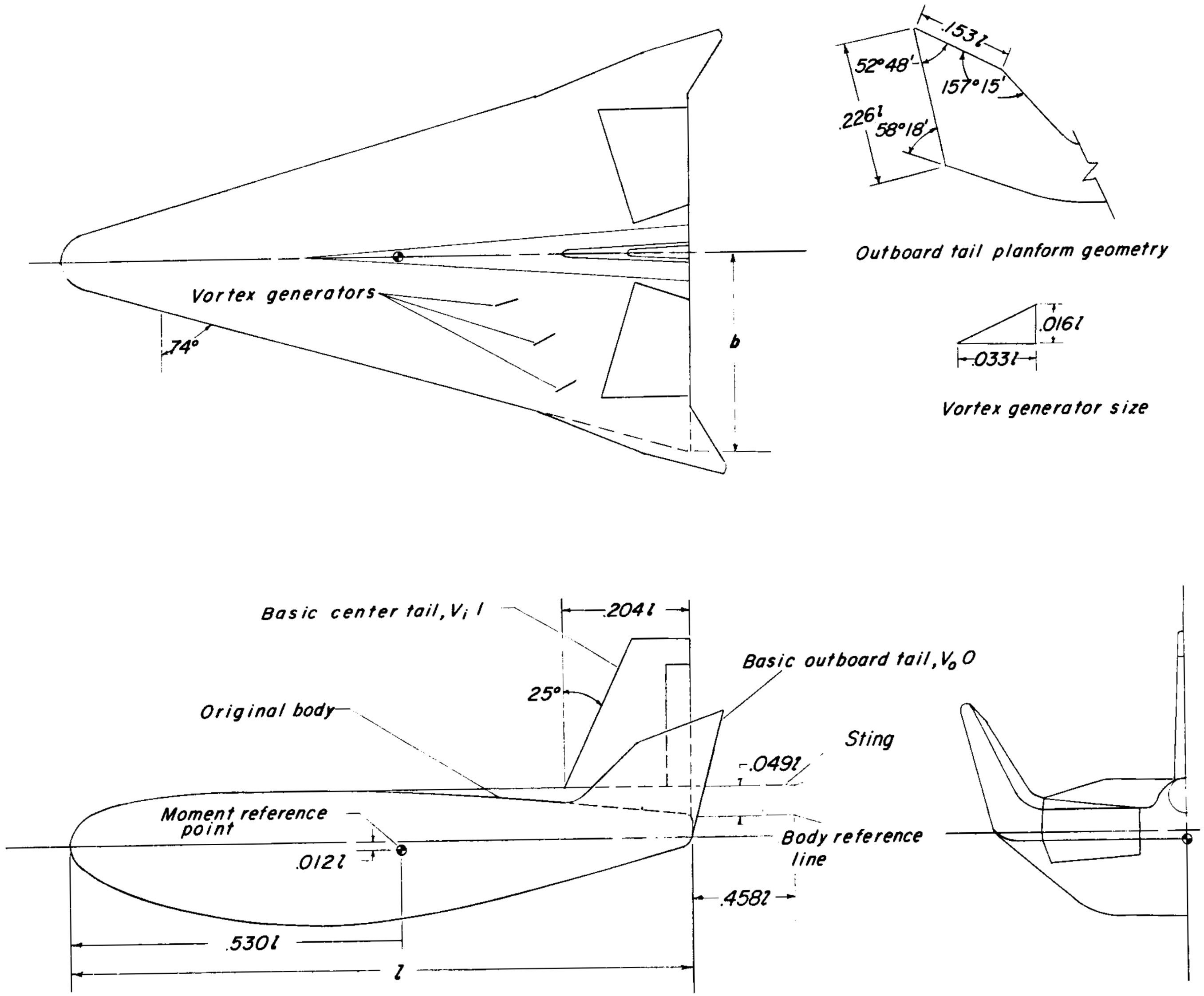
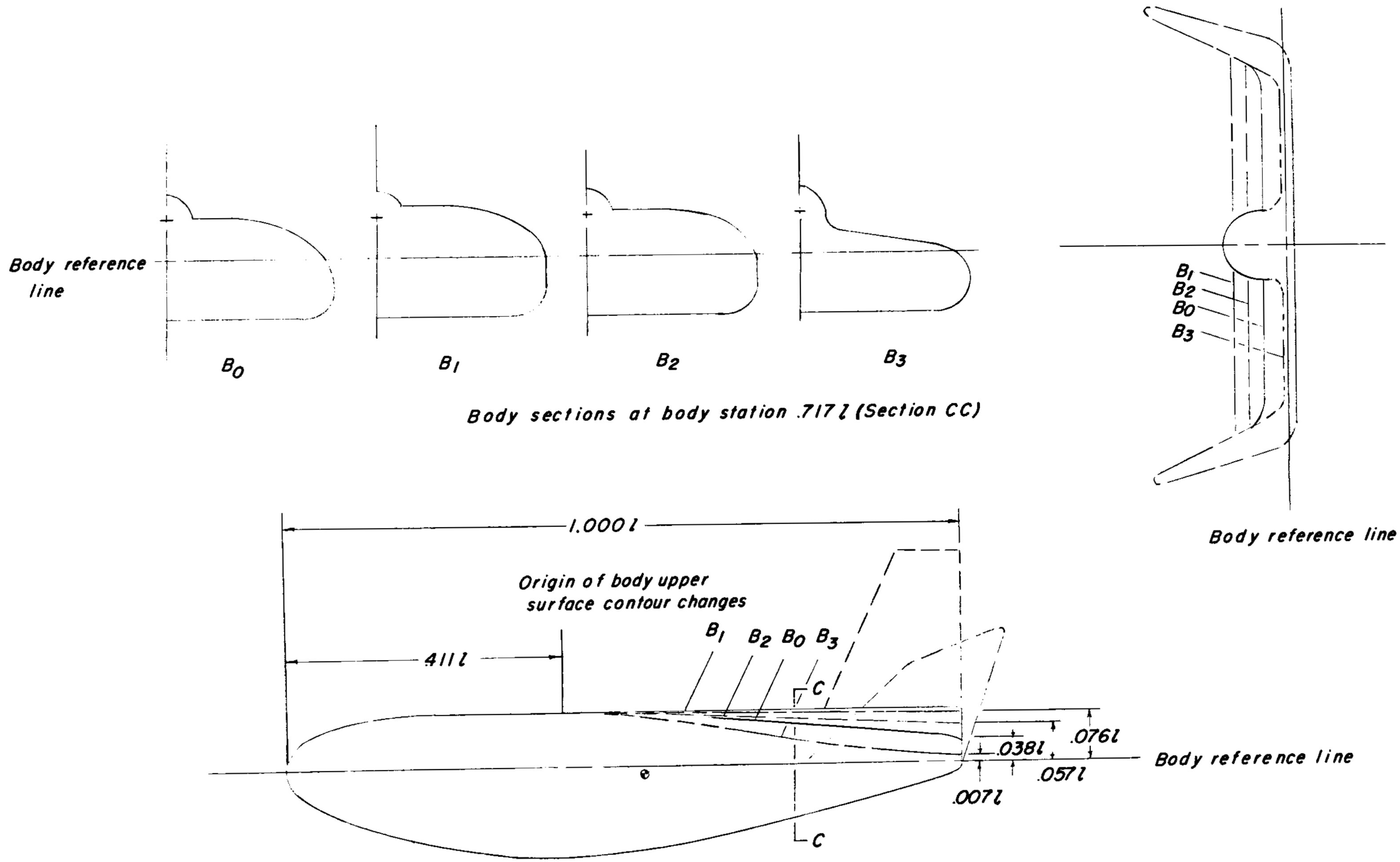


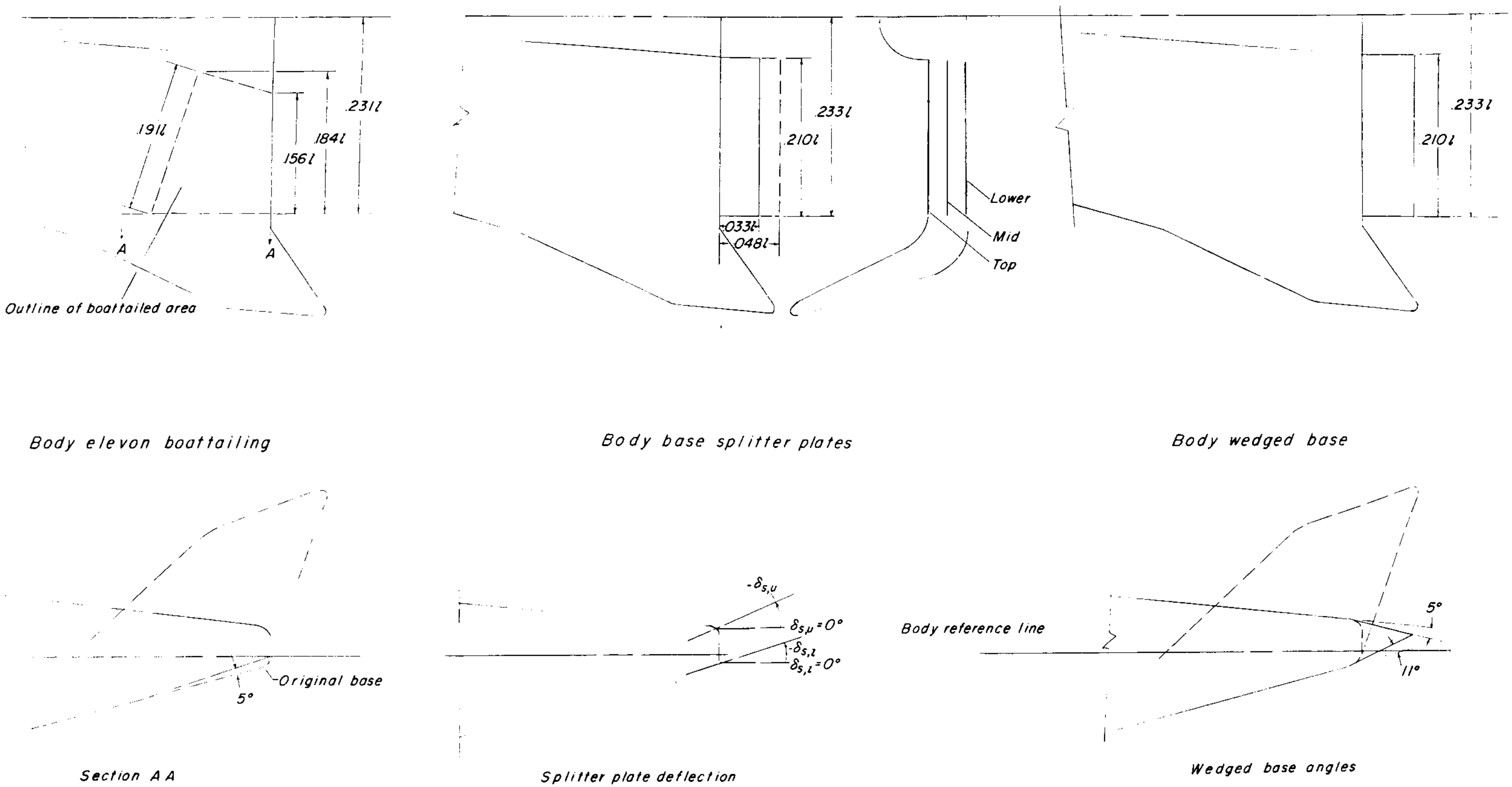
(a) Basic configuration $B_0V_i1V_o0$.

Figure 1.- HL-10 model drawing showing various configurations tested.



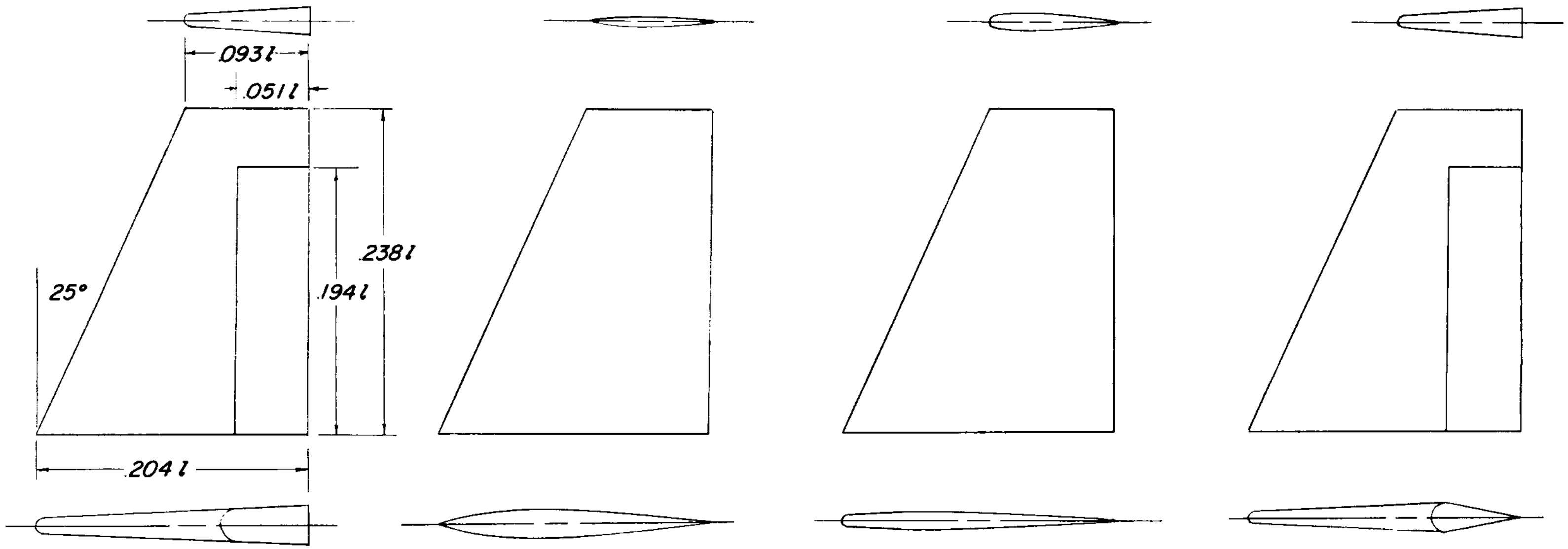
(b) Variations in body geometry.

Figure 1.- Continued.



(c) Changes in HL-10 afterbody.

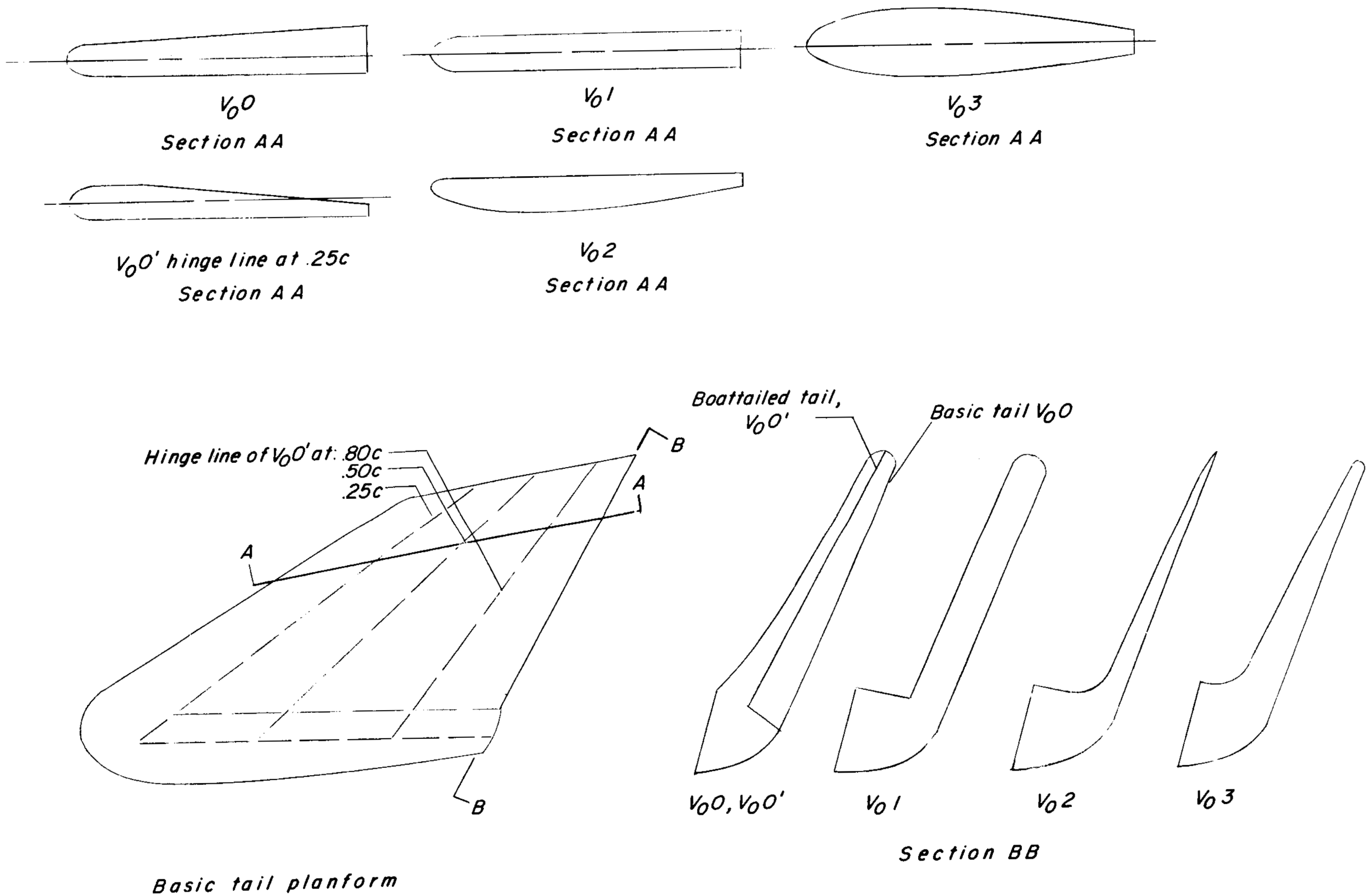
Figure 1.- Continued.



Basic tail, V_i 1 | NACA 65-006 airfoil section, V_i 2 | Basic tail, beveled from 25 percent chord, V_i 3 | Basic tail, beveled rudder only, V_i 4

(d) Changes in center vertical-tail cross section. All tails have same planform geometry.

Figure 1.- Continued.



(e) Geometric variations in outboard-tail geometry. (V_0).

Figure 1.- Concluded.

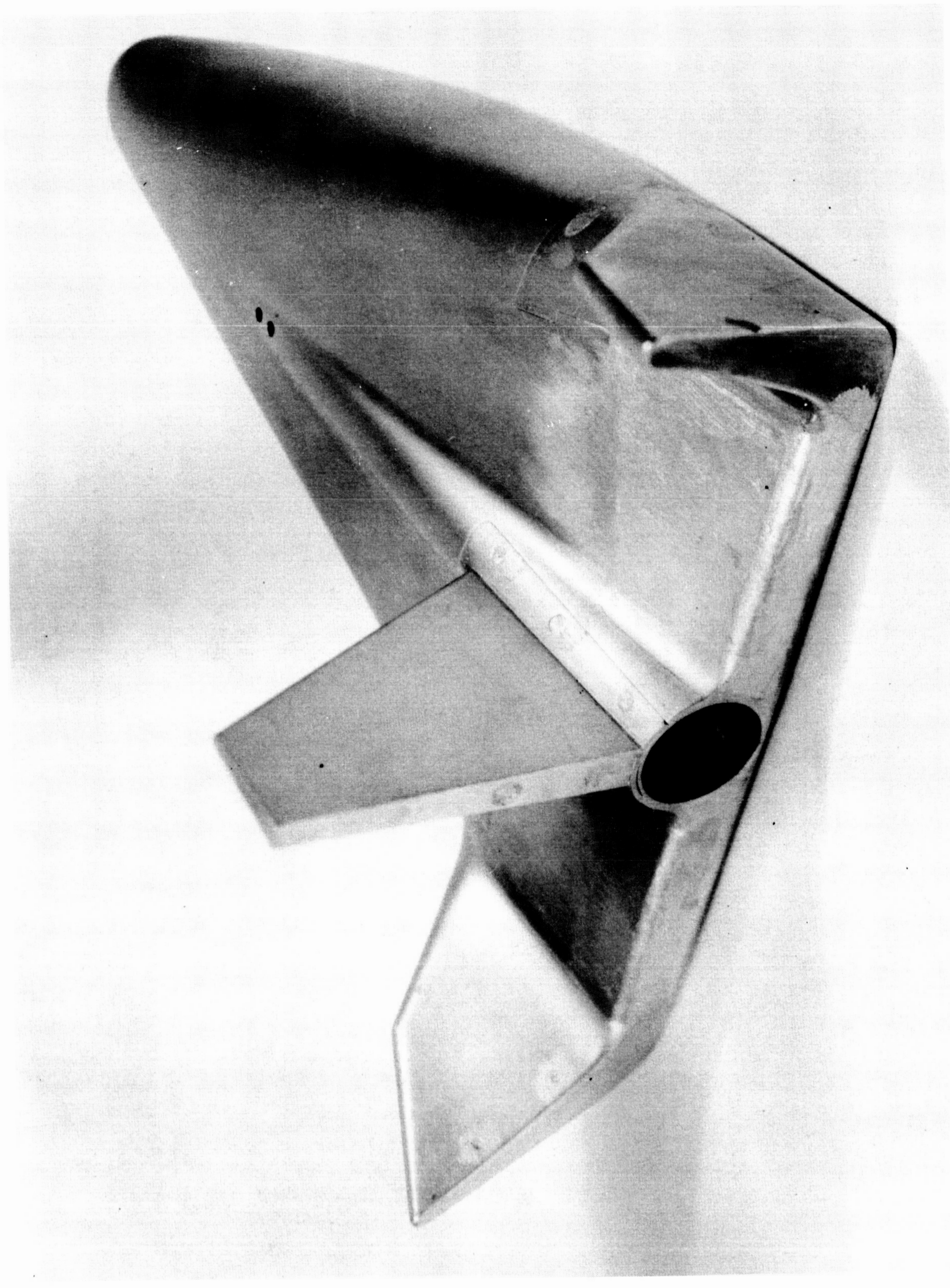


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Figure 2.- Photograph of model of HL-10 configuration.

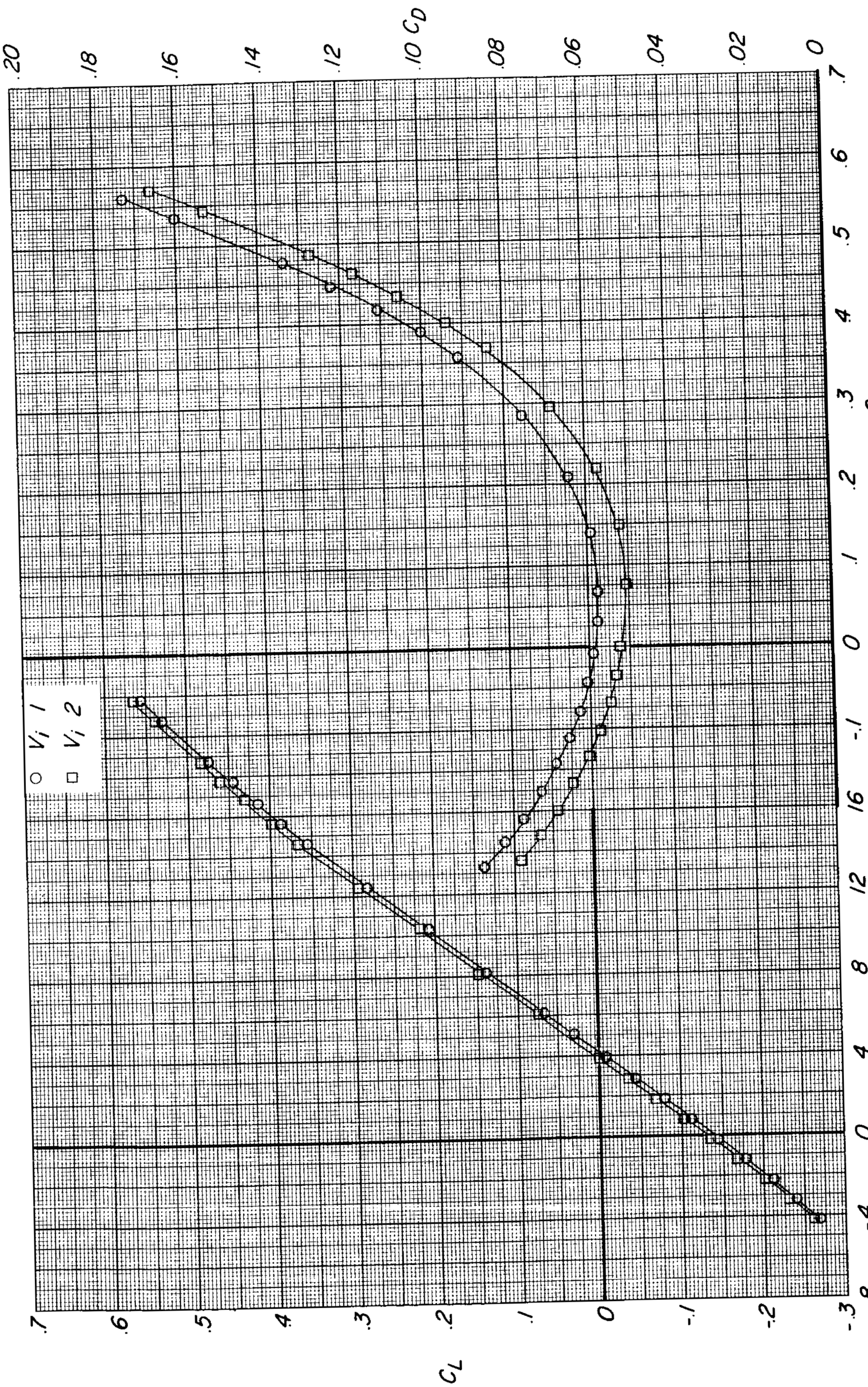
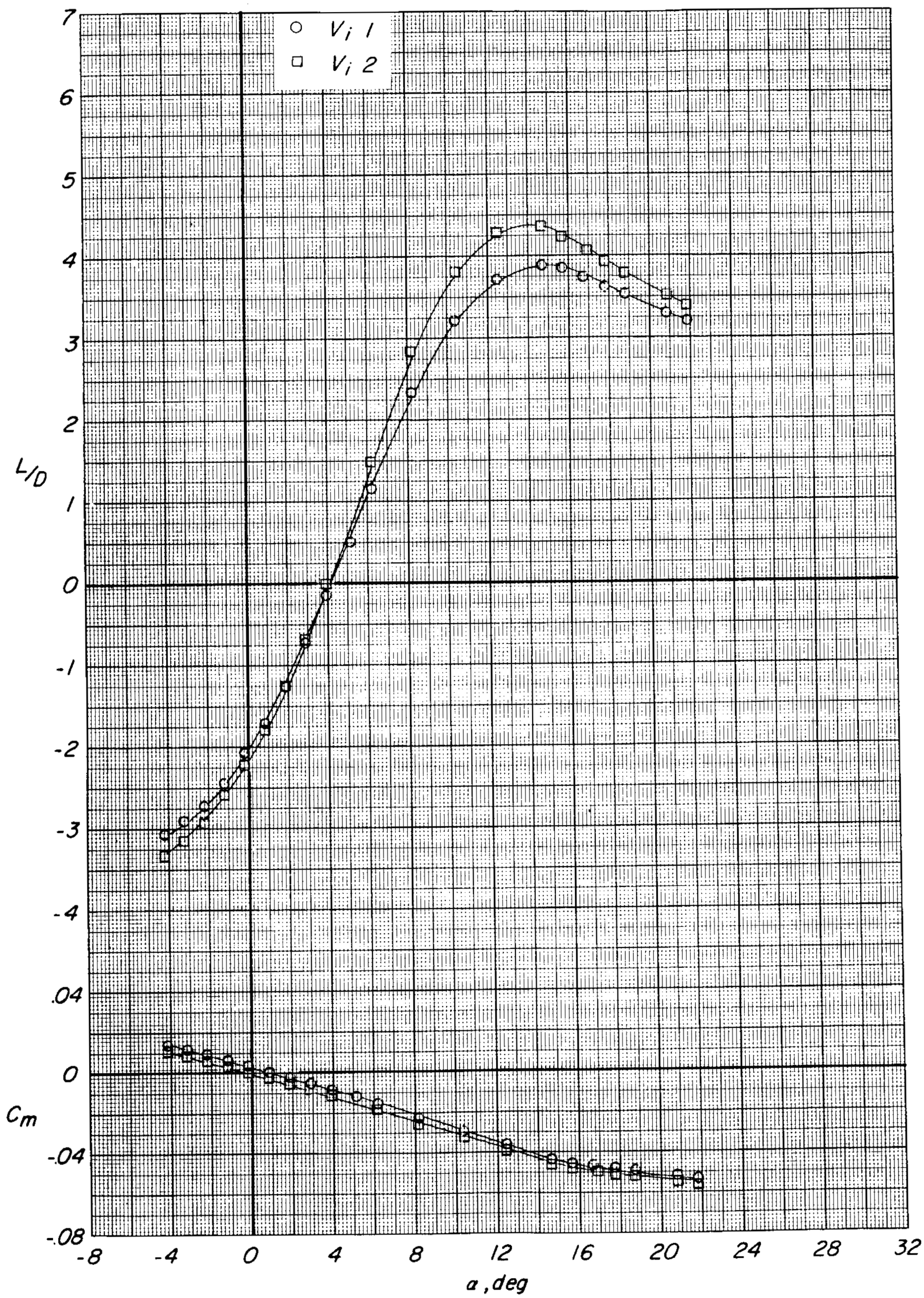


Figure 3.- Effects of changing center-line vertical-tail geometry. Configuration B_0V_00.



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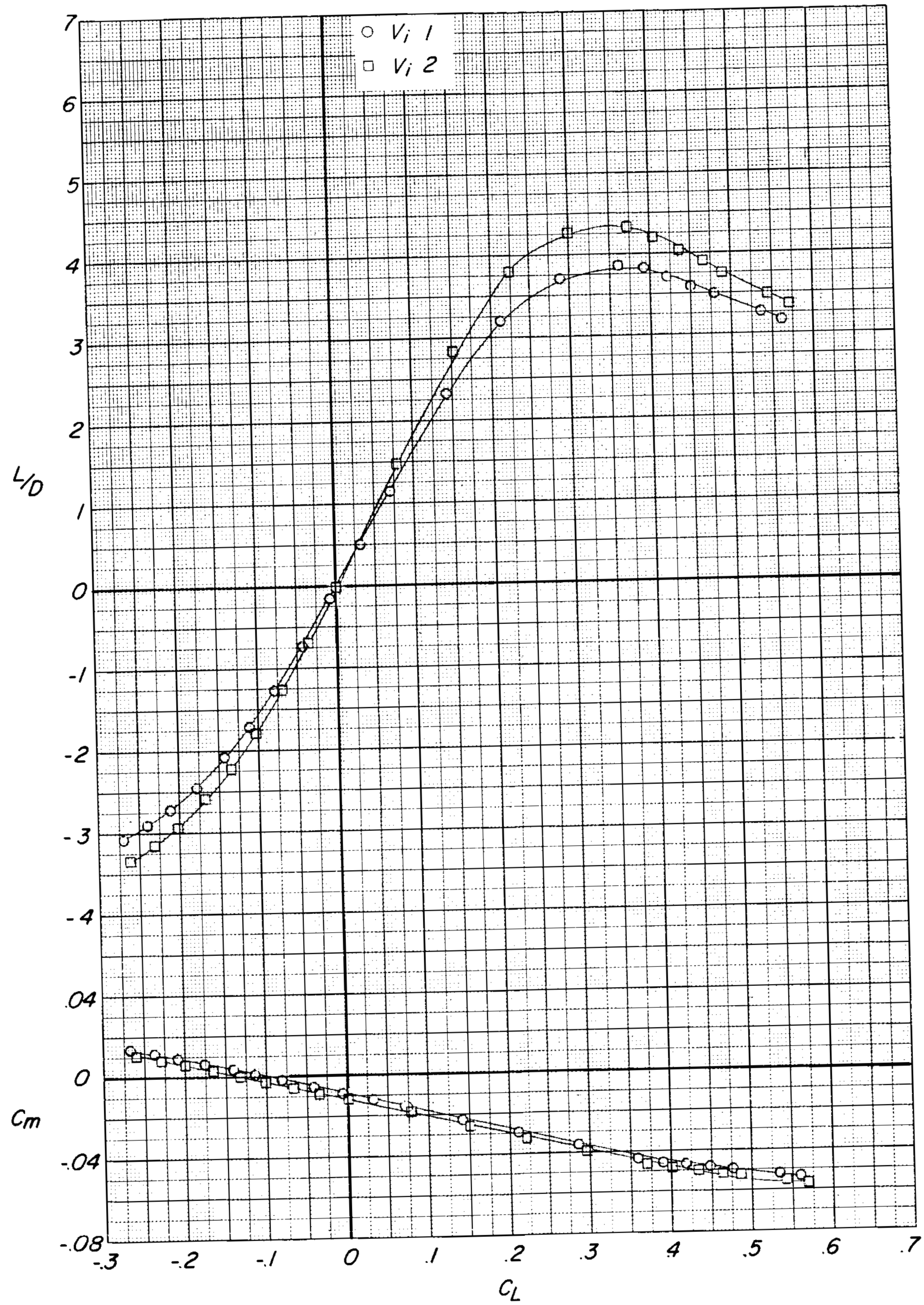

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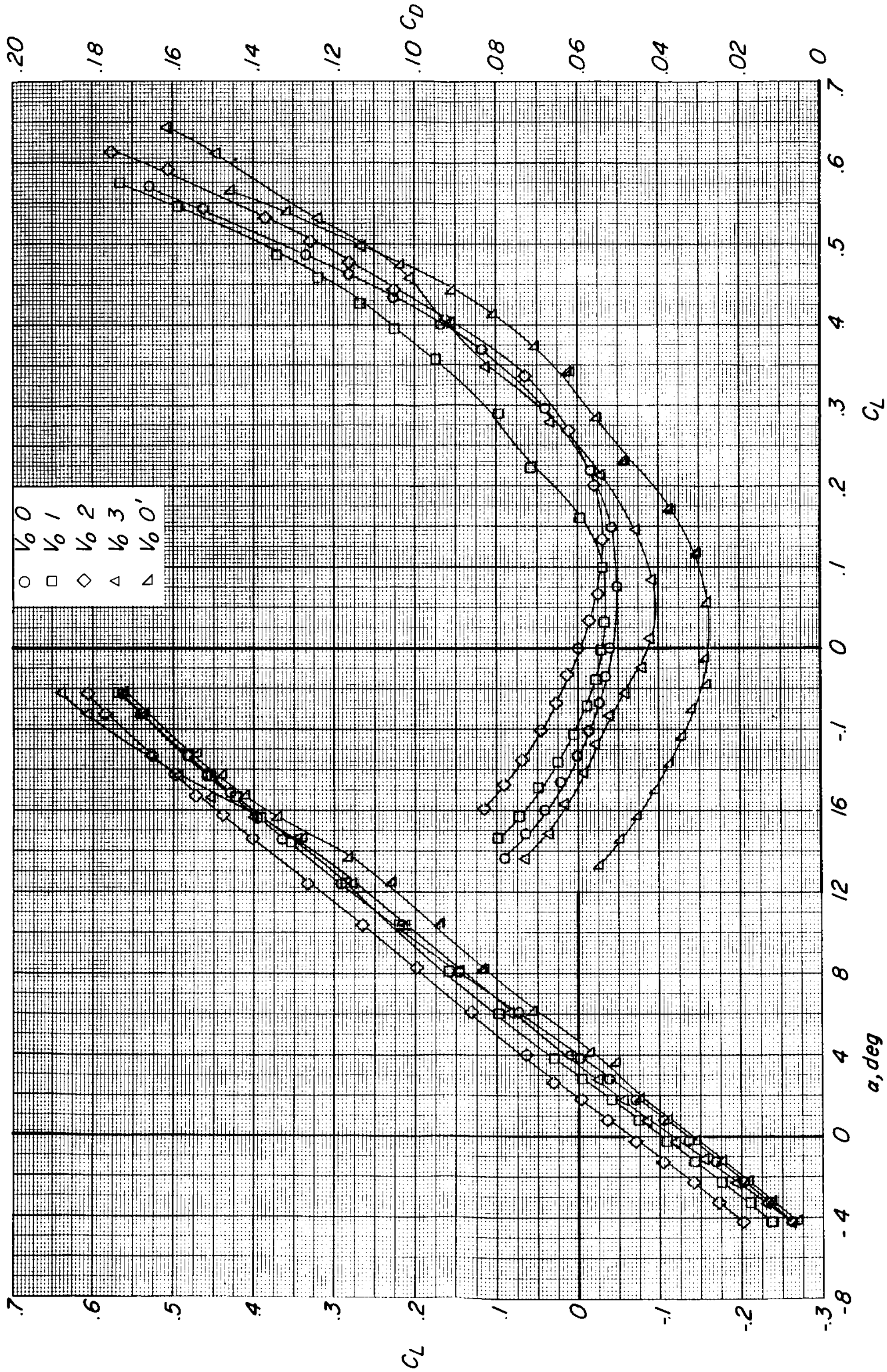
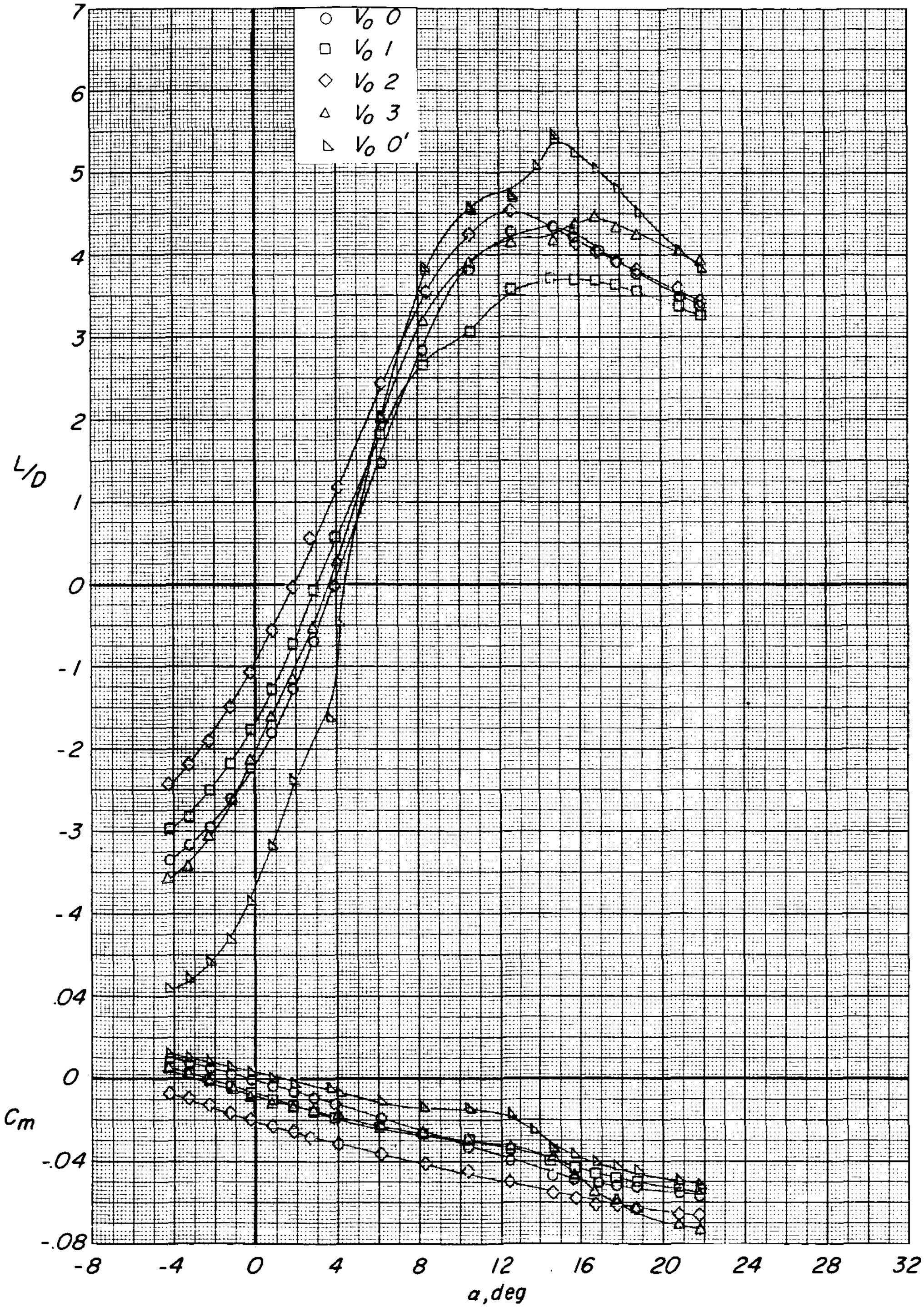


Figure 4.- Effects of changing outboard vertical-tail geometry. Configuration B_0V_i2. Hinge line for $V_0 0'$ at 25 percent tail chord.



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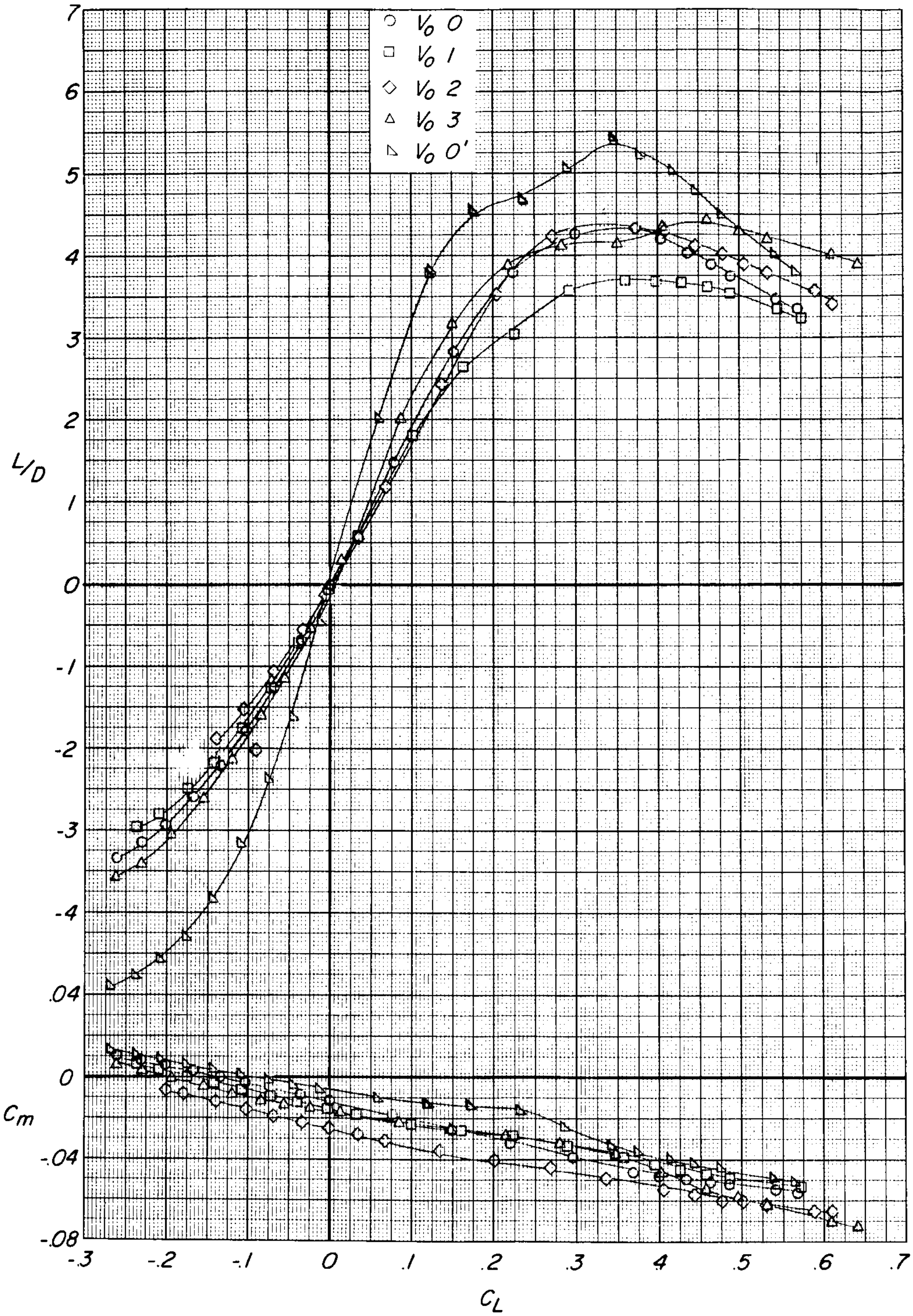

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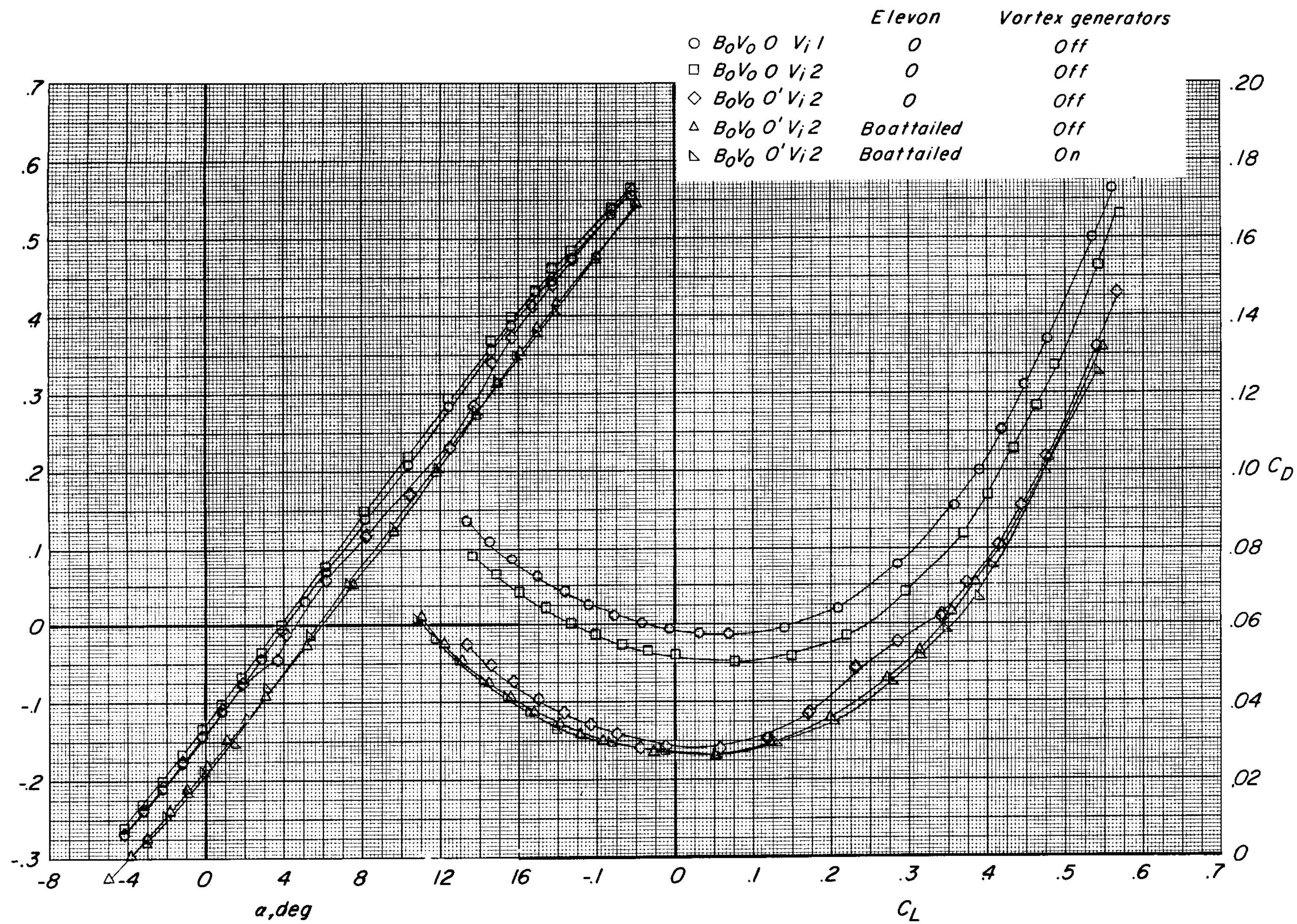
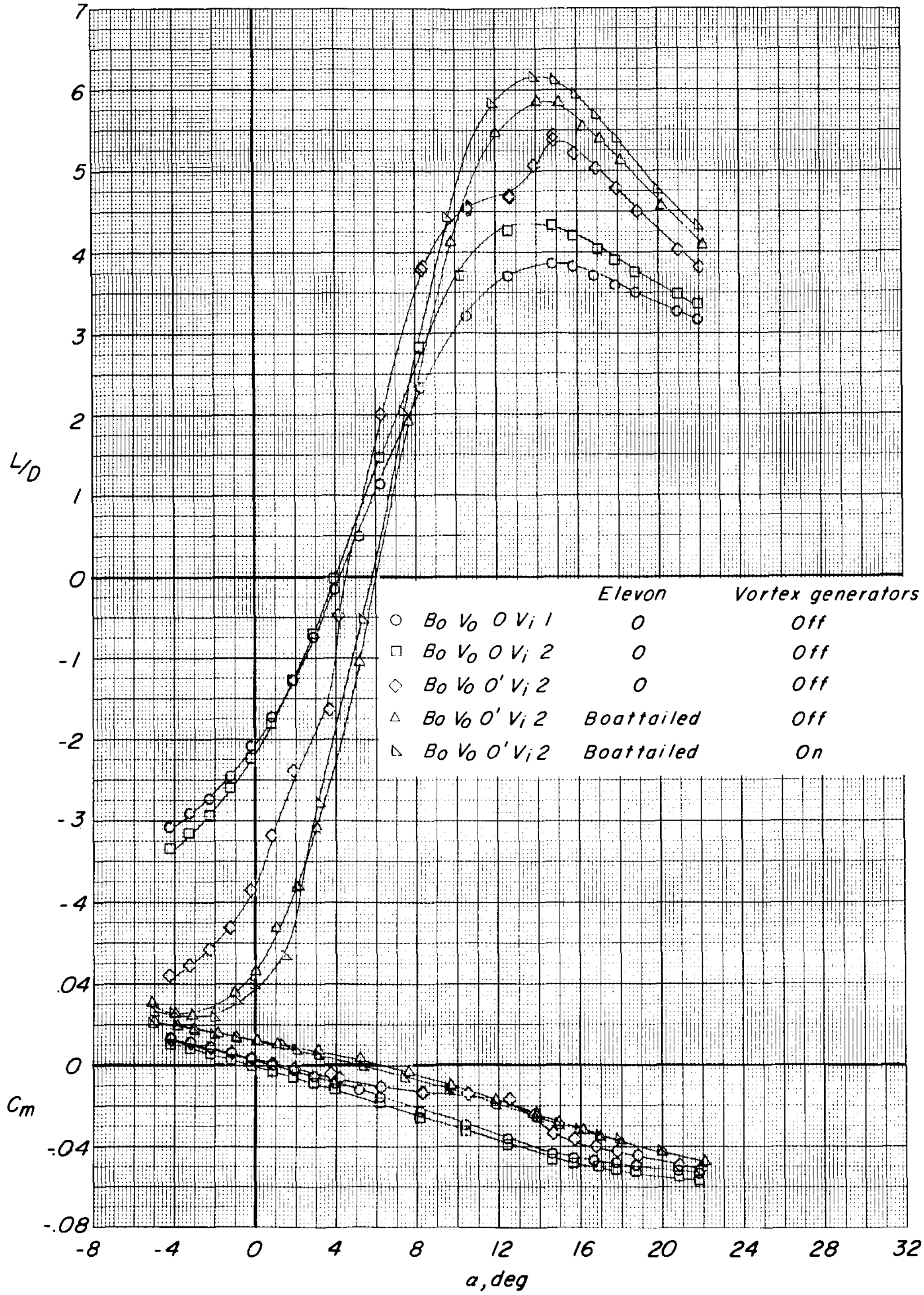


Figure 5.- Basic HL-10 configuration with various combinations of geometric modifications. Configuration B_0. Hinge line for V_00' at 25 percent tail chord.



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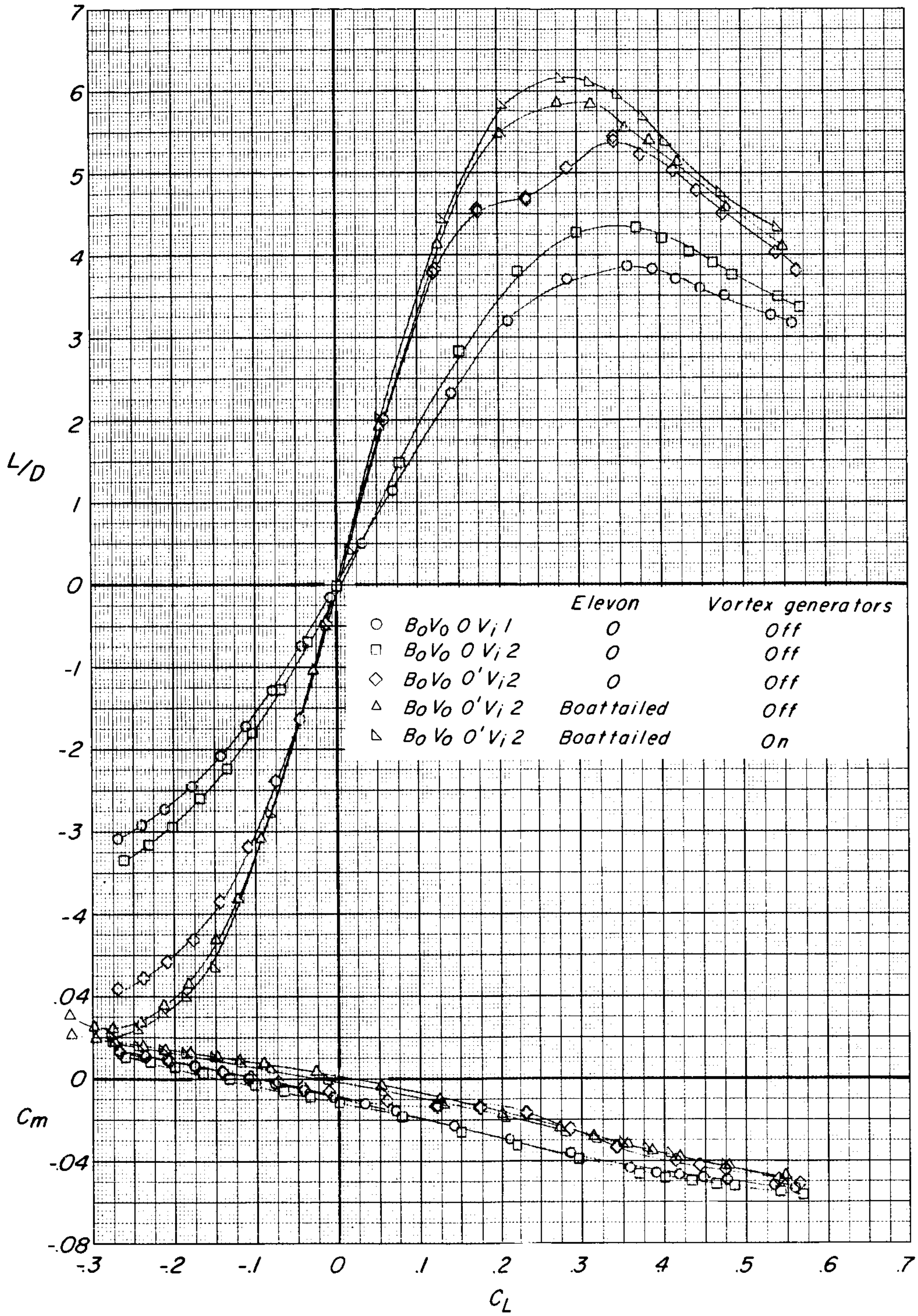

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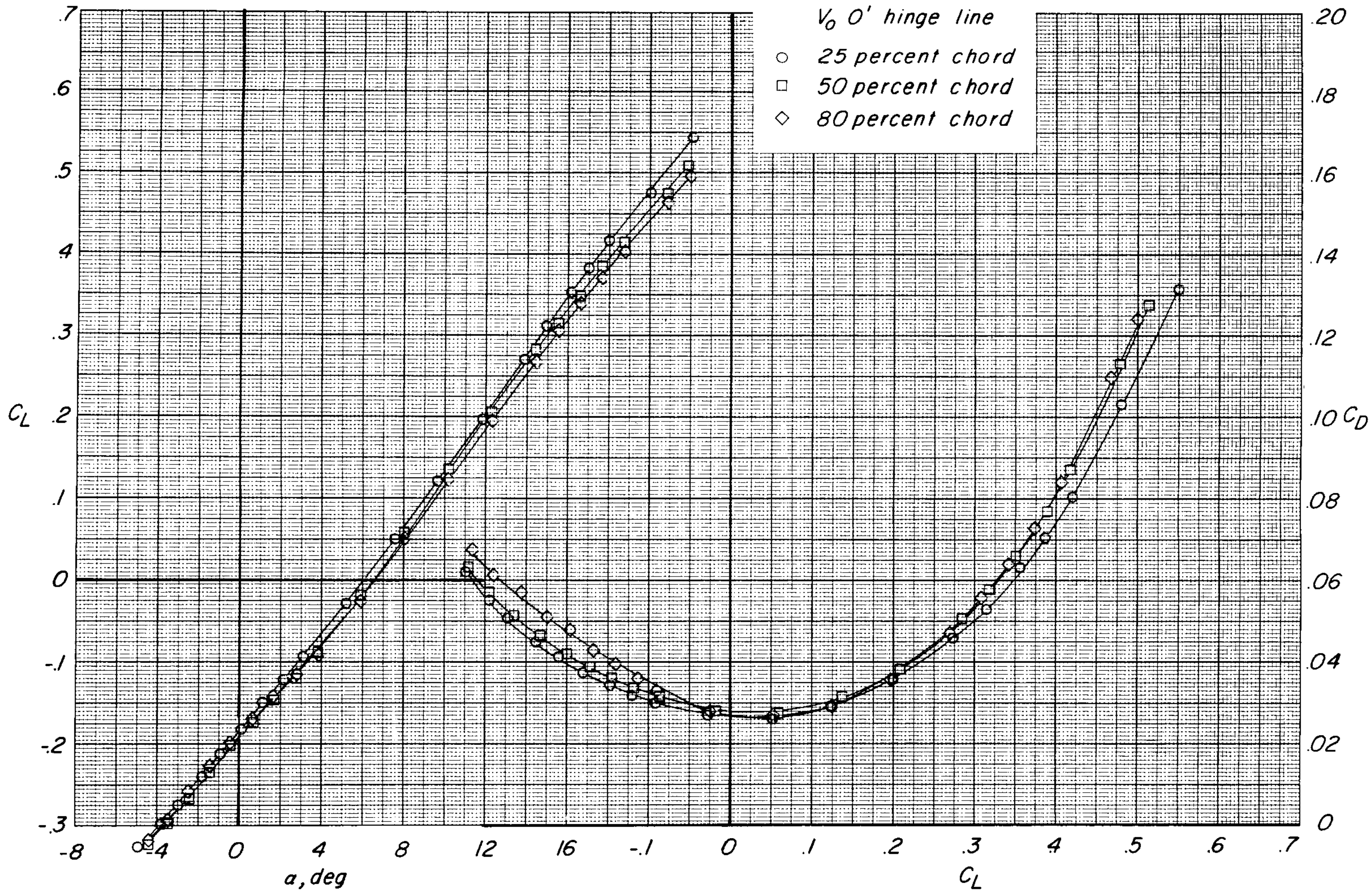
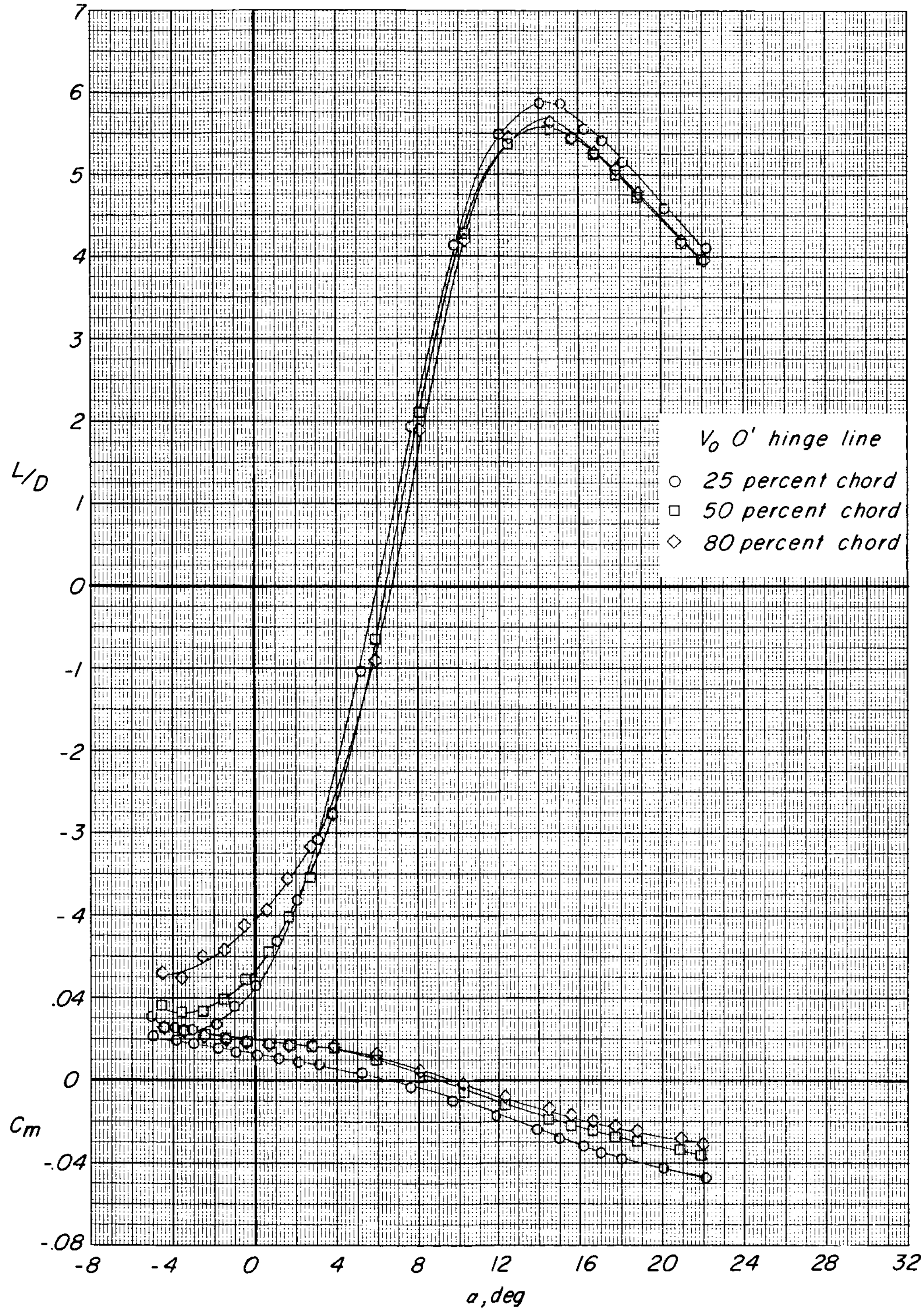


Figure 6.- Effects of outboard-tail hinge-line location. Configuration $B_0V_i2V_00'$. Bottom elevon surface boattailed.



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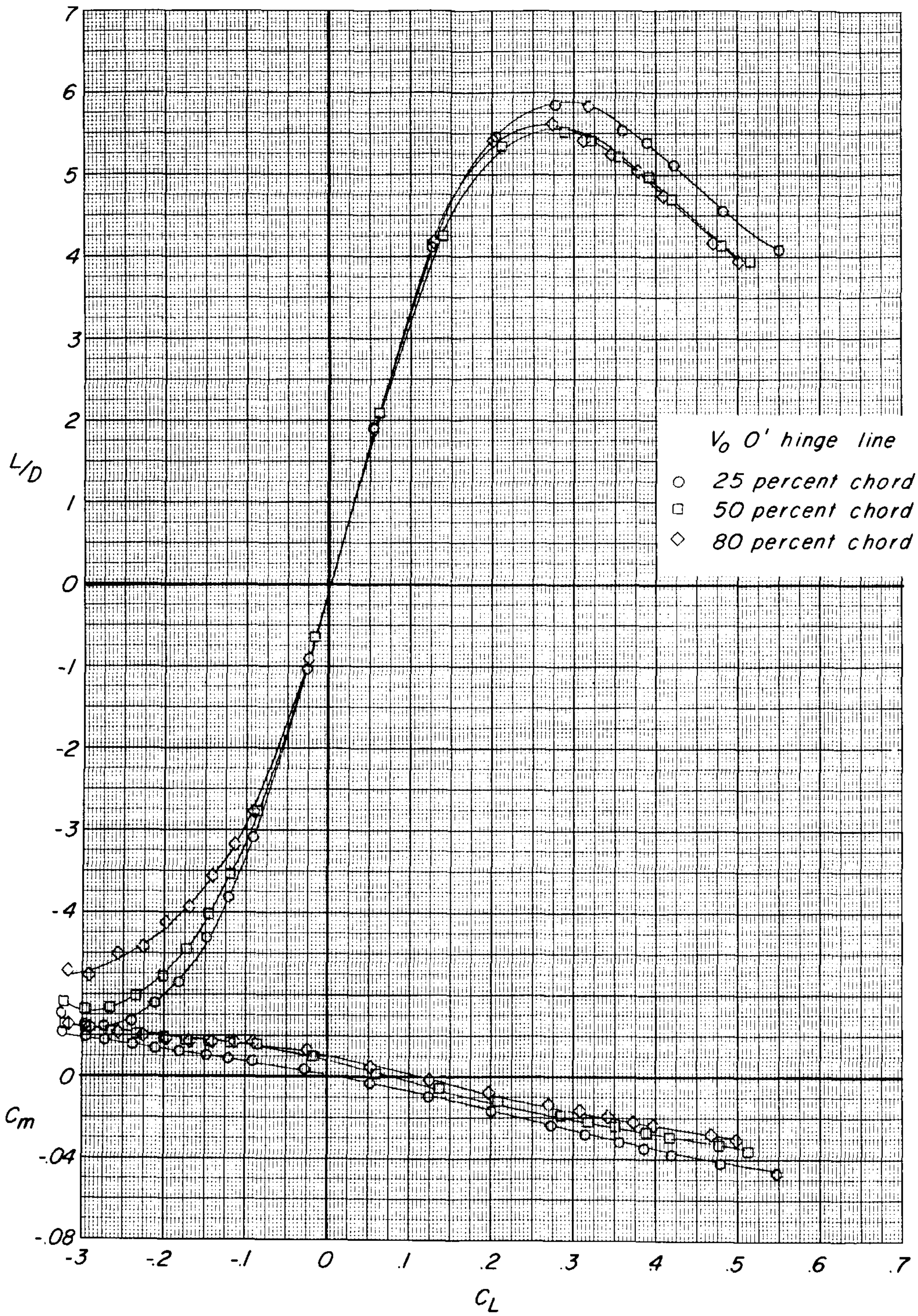

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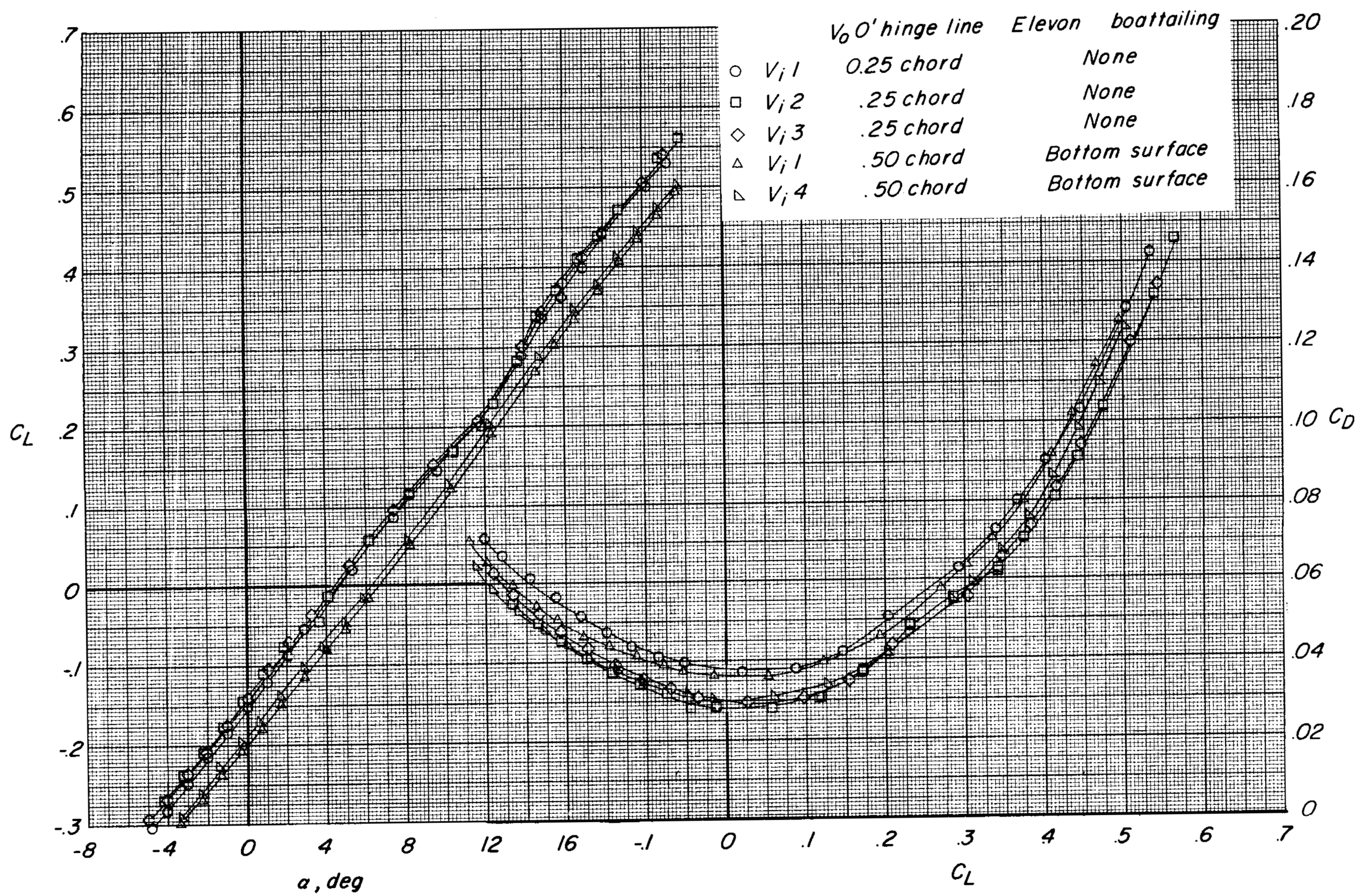

Figure 7.- Effects of changing center-line vertical-tail geometry. Configuration B_0V_00'.

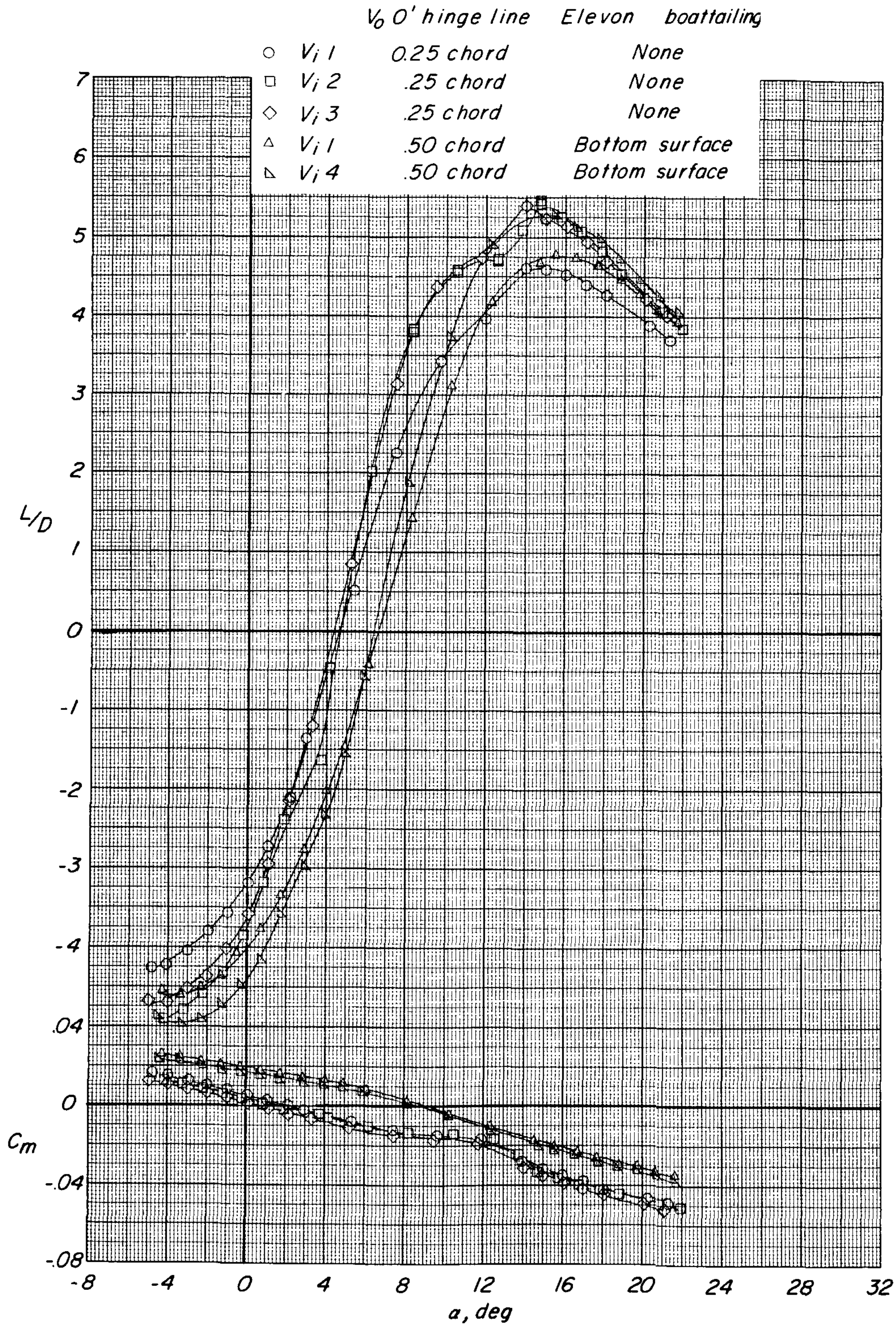

Figure 7.- Continued.

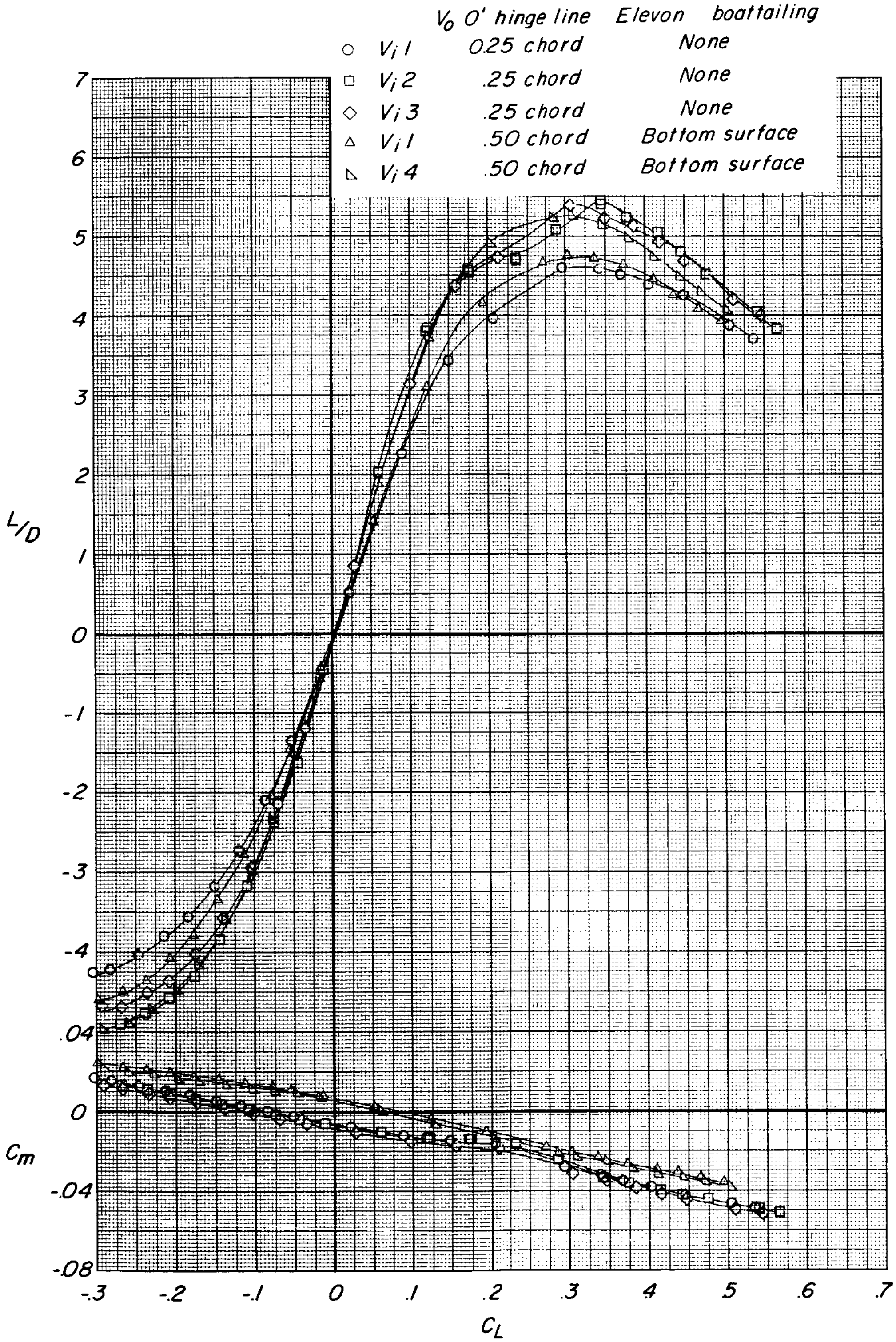

Figure 7.- Concluded.

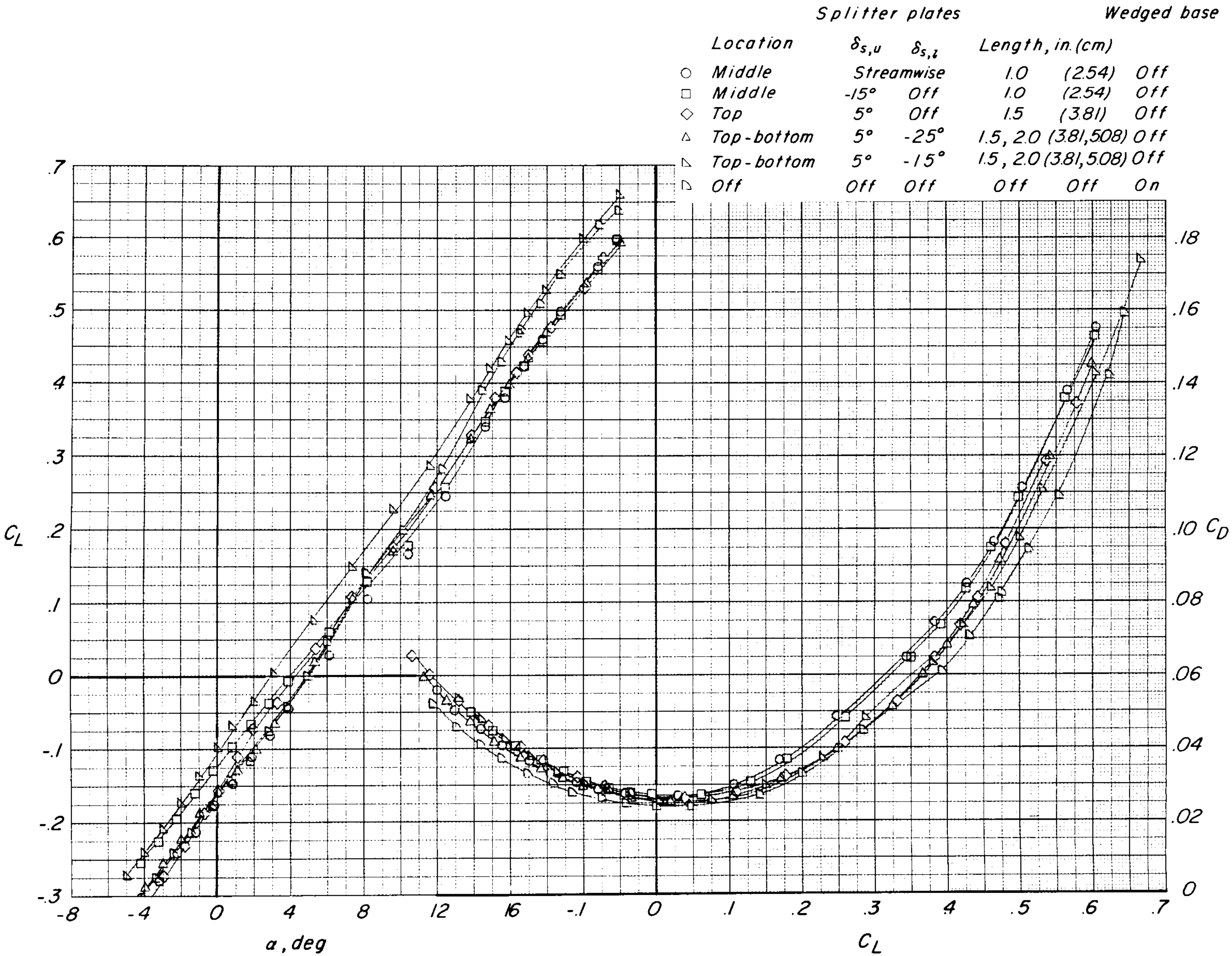

Figure 8.- Effects of body-base modifications. Configuration $B_0V_i2V_00'$. Hinge line for V_00' at 25 percent tail chord.

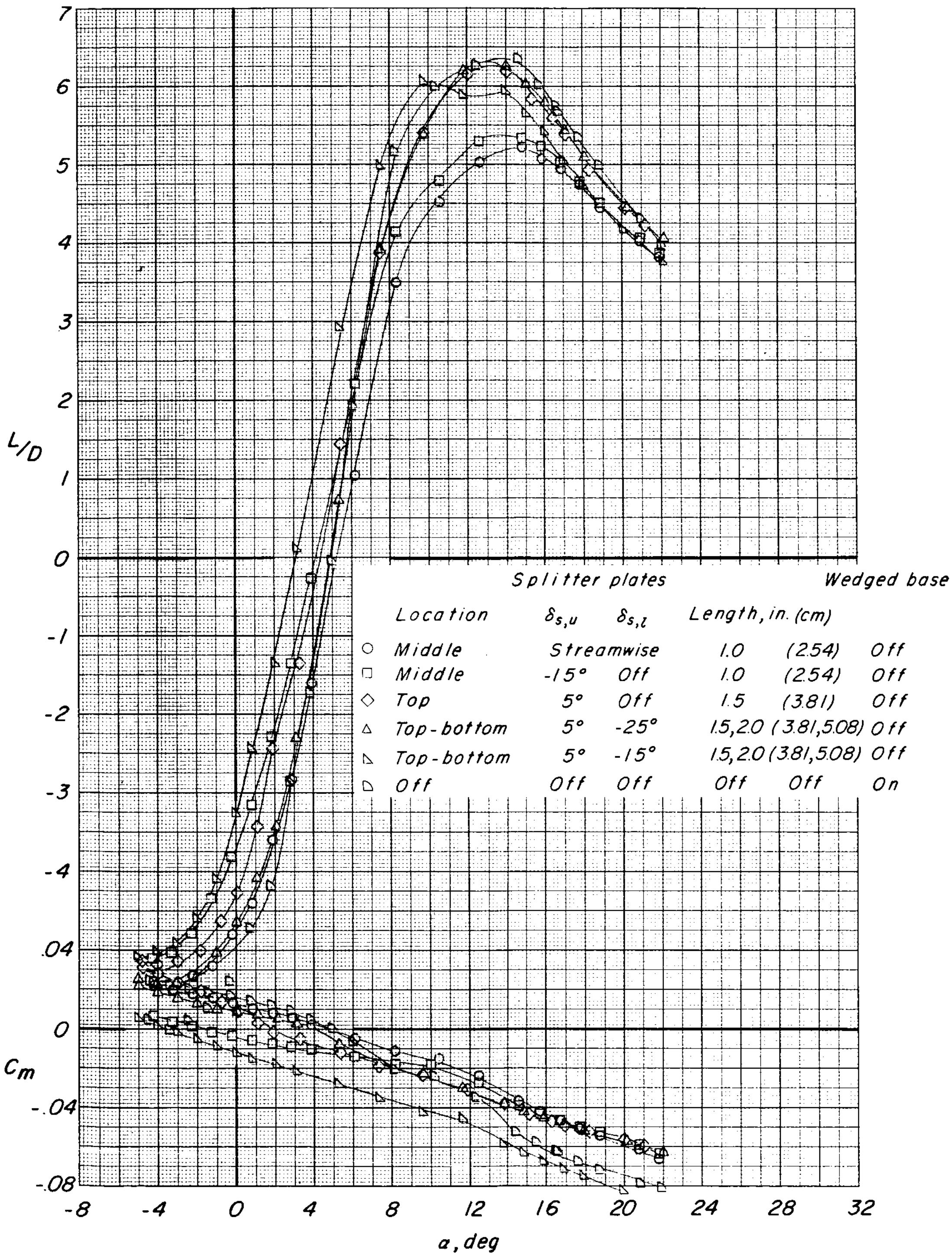

Figure 8.- Continued.

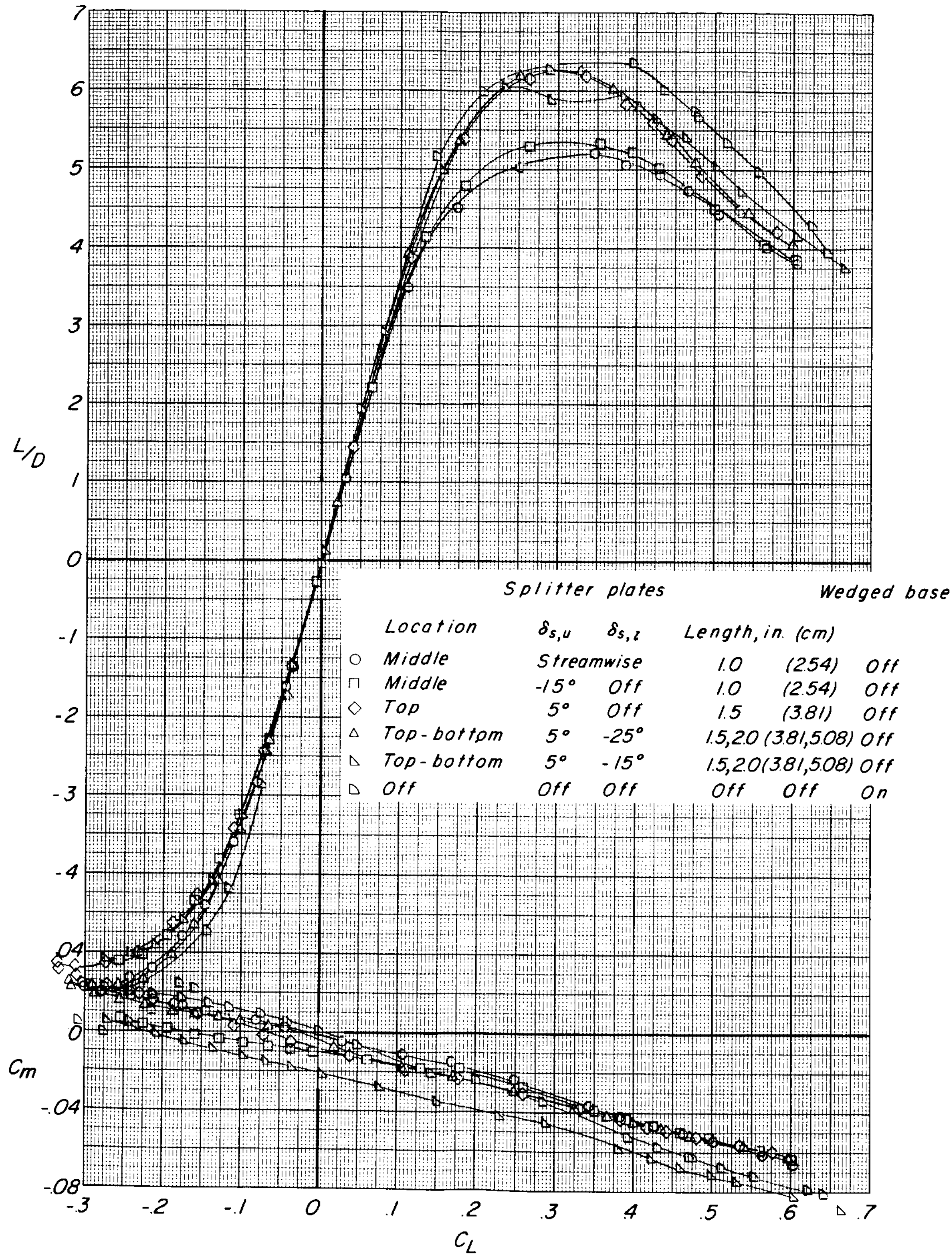

Figure 8.- Concluded.

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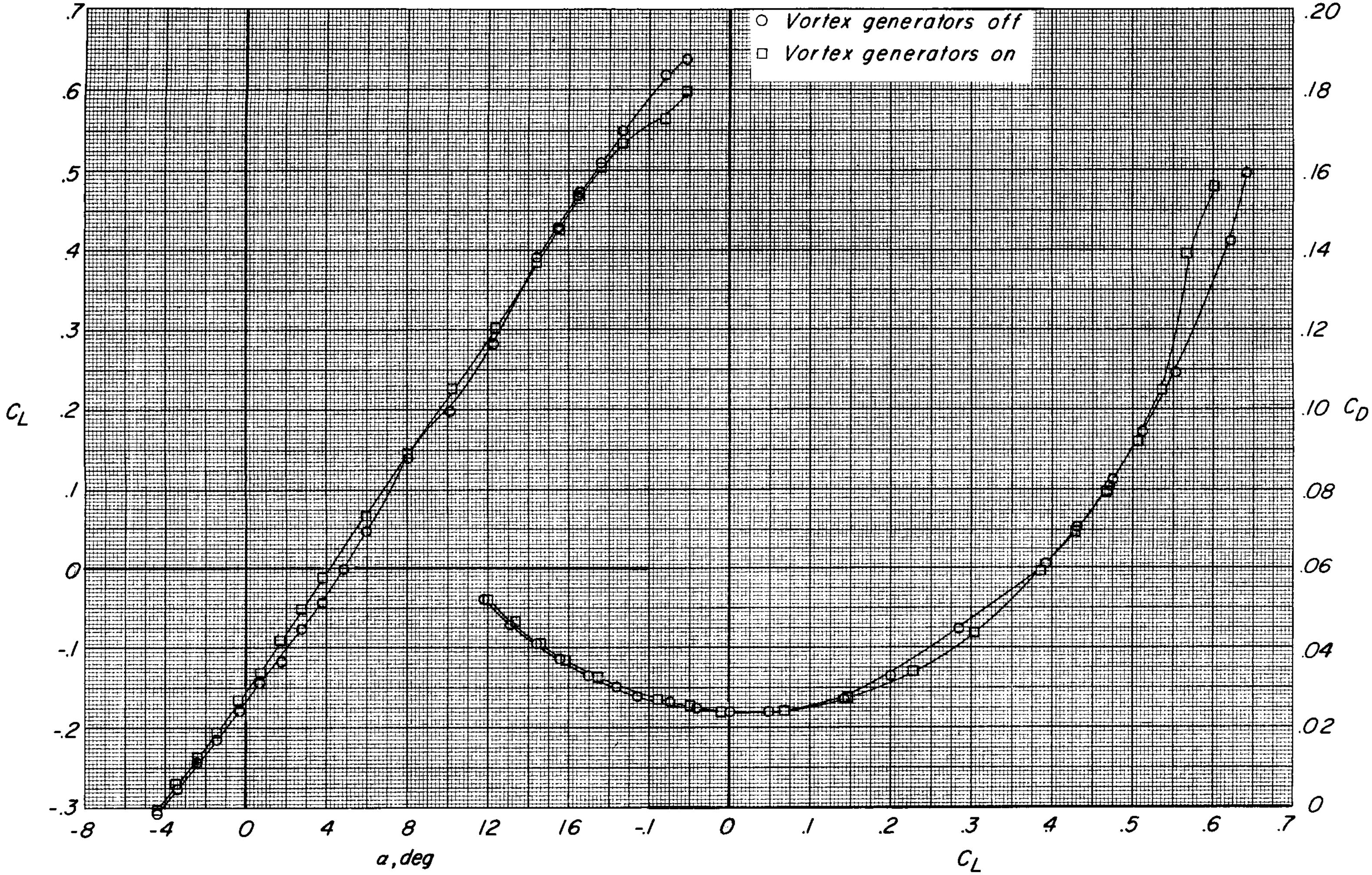

Figure 9.- Effects of addition of vortex generators to upper surface of basic body B_0 with wedged base. Configuration $B_0V_i2V_o0'$. Hinge line for V_o0' at 25 percent chord.

[redacted]

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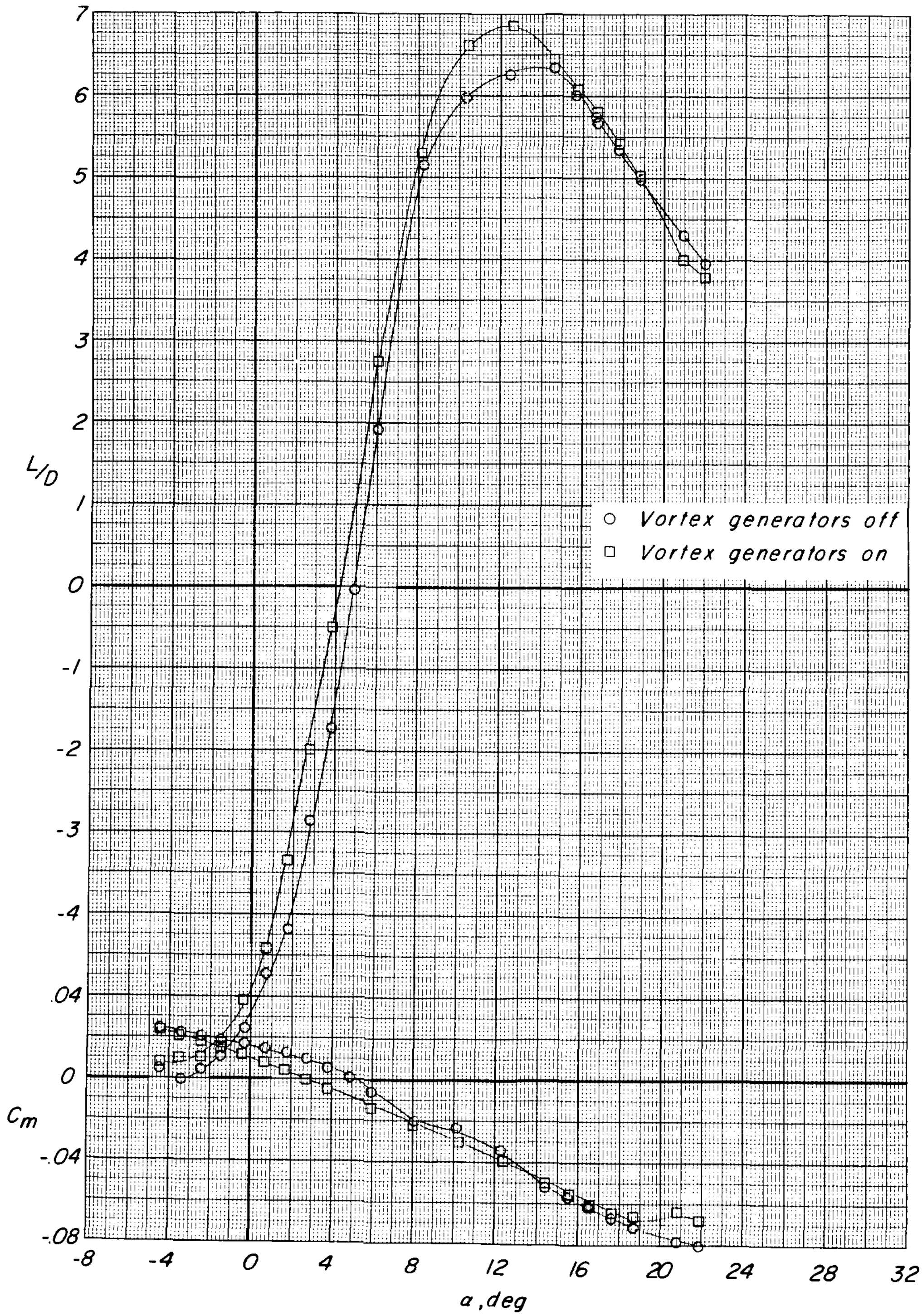
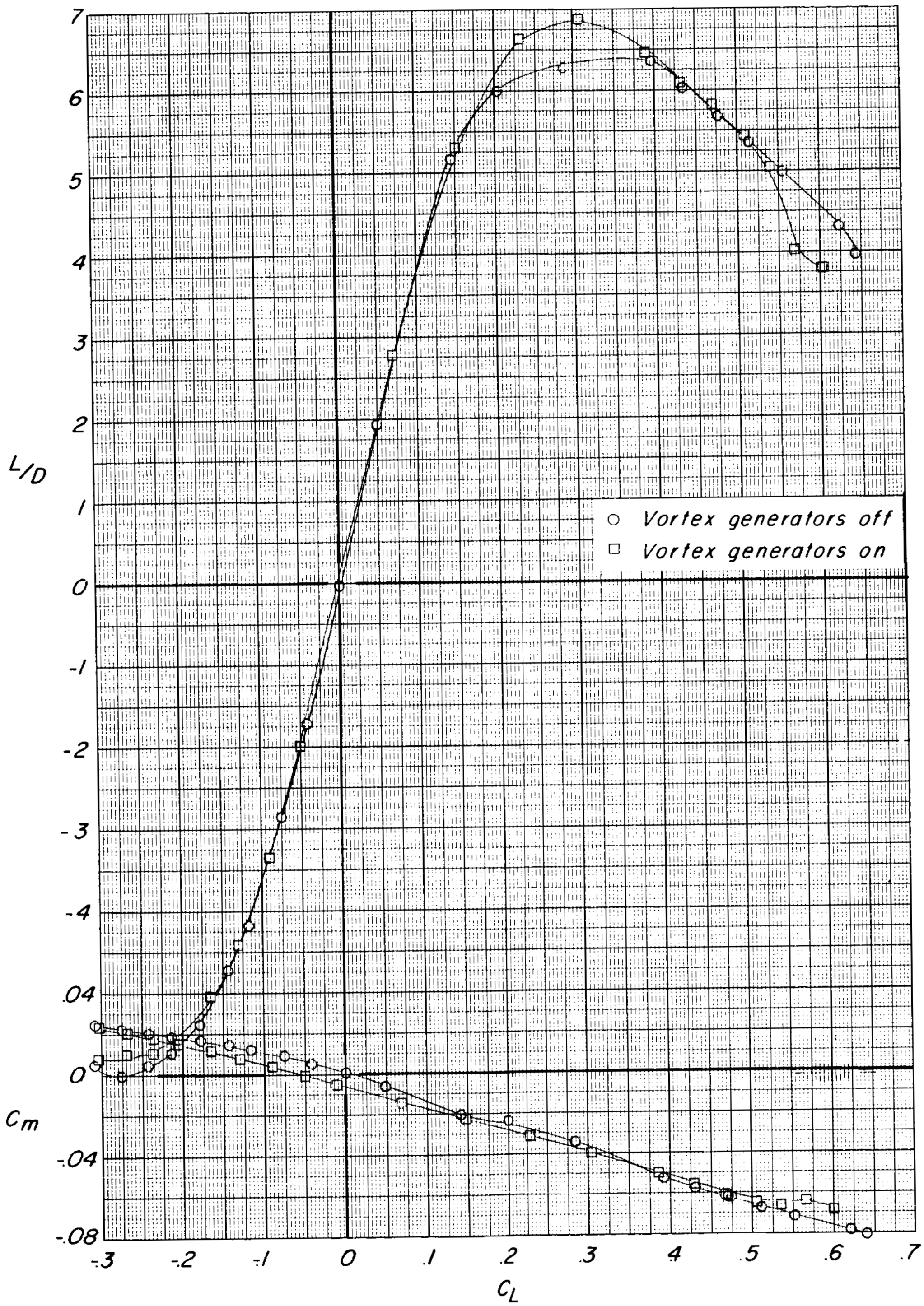


Figure 9.- Continued.



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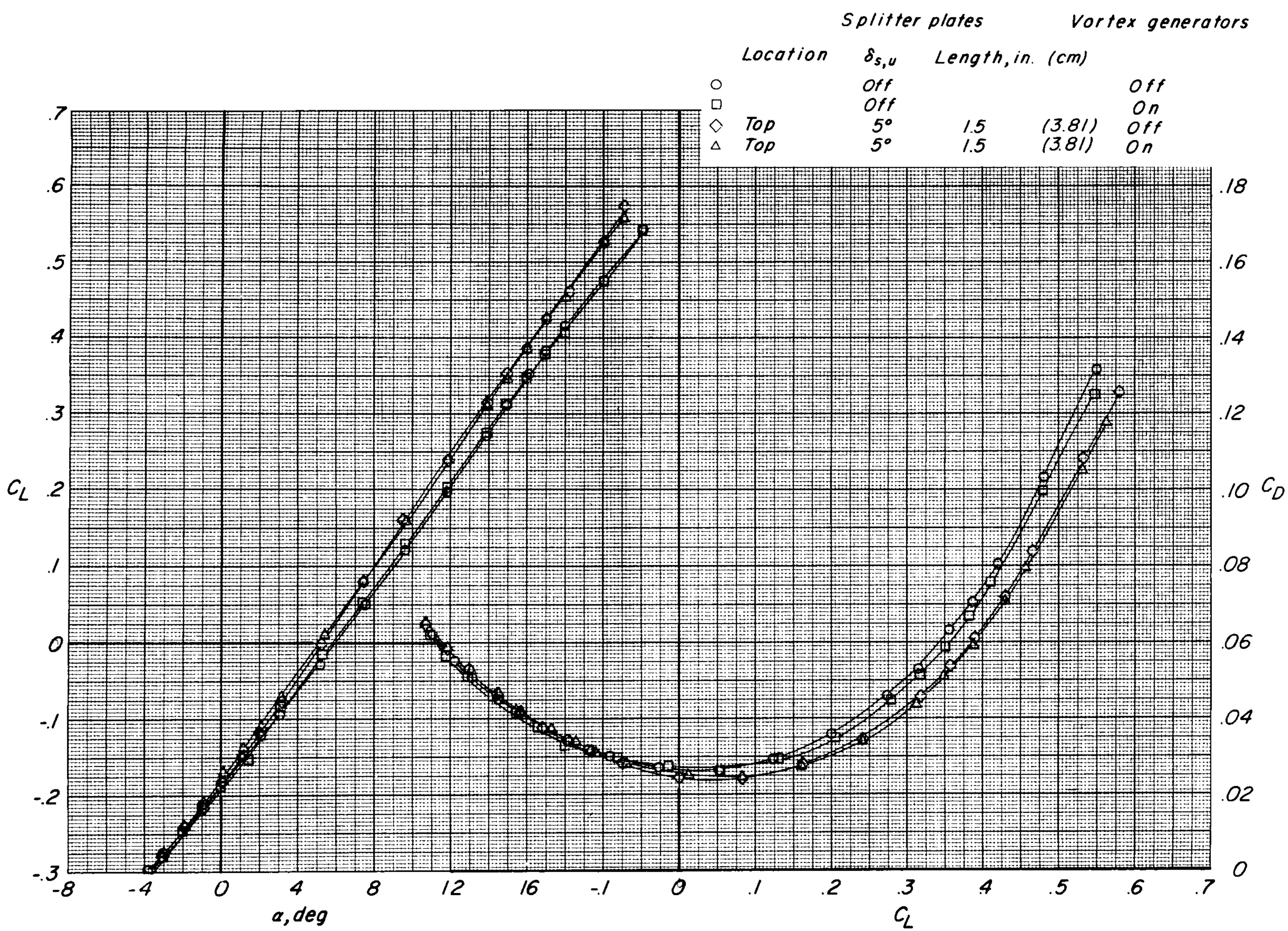


Figure 10.- Effects of addition of splitter plates and vortex generators to configuration having bottom elevon surface boattailed. Configuration $B_0V_i2V_00'$. Hinge line for V_00' at 25 percent chord.

[redacted]

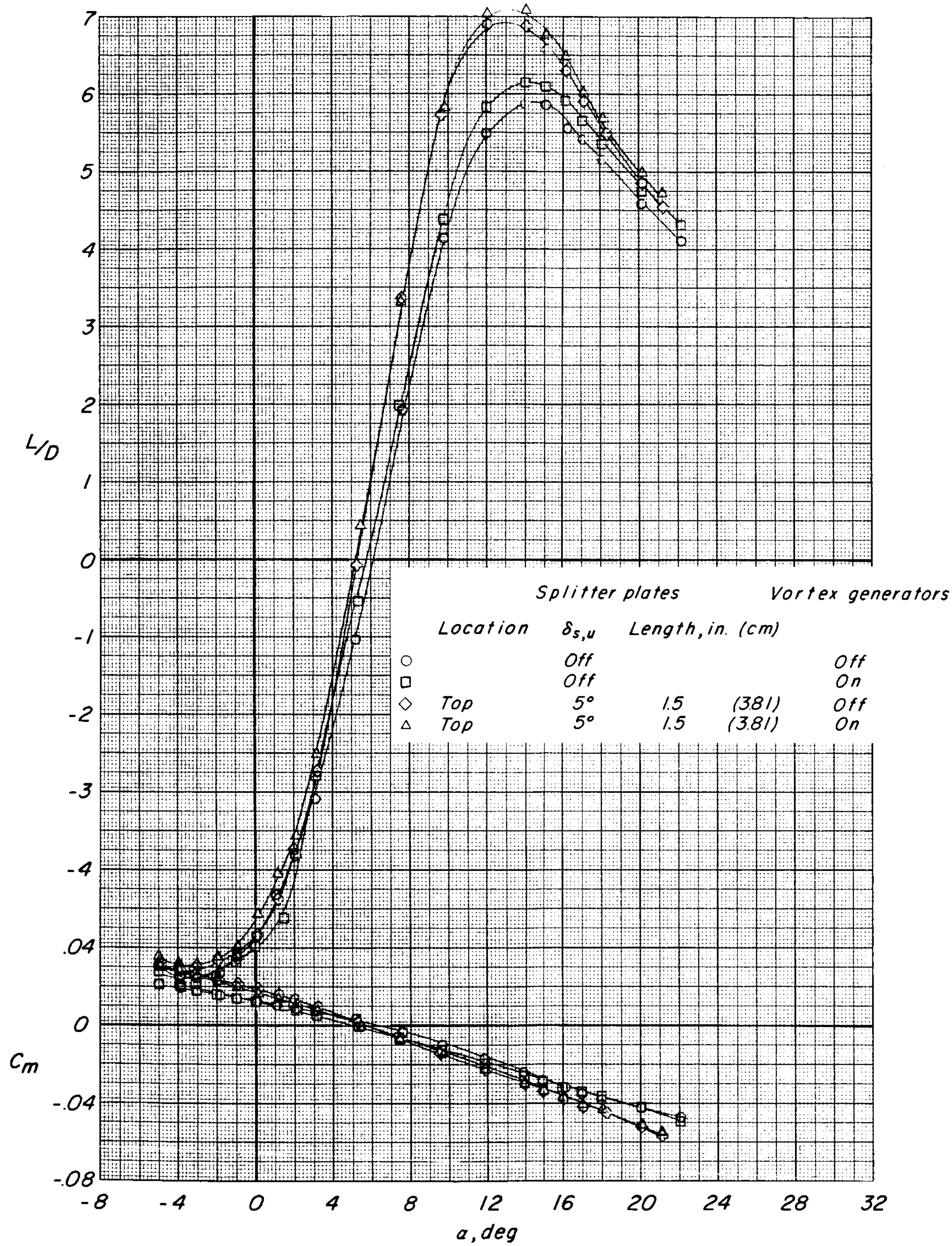
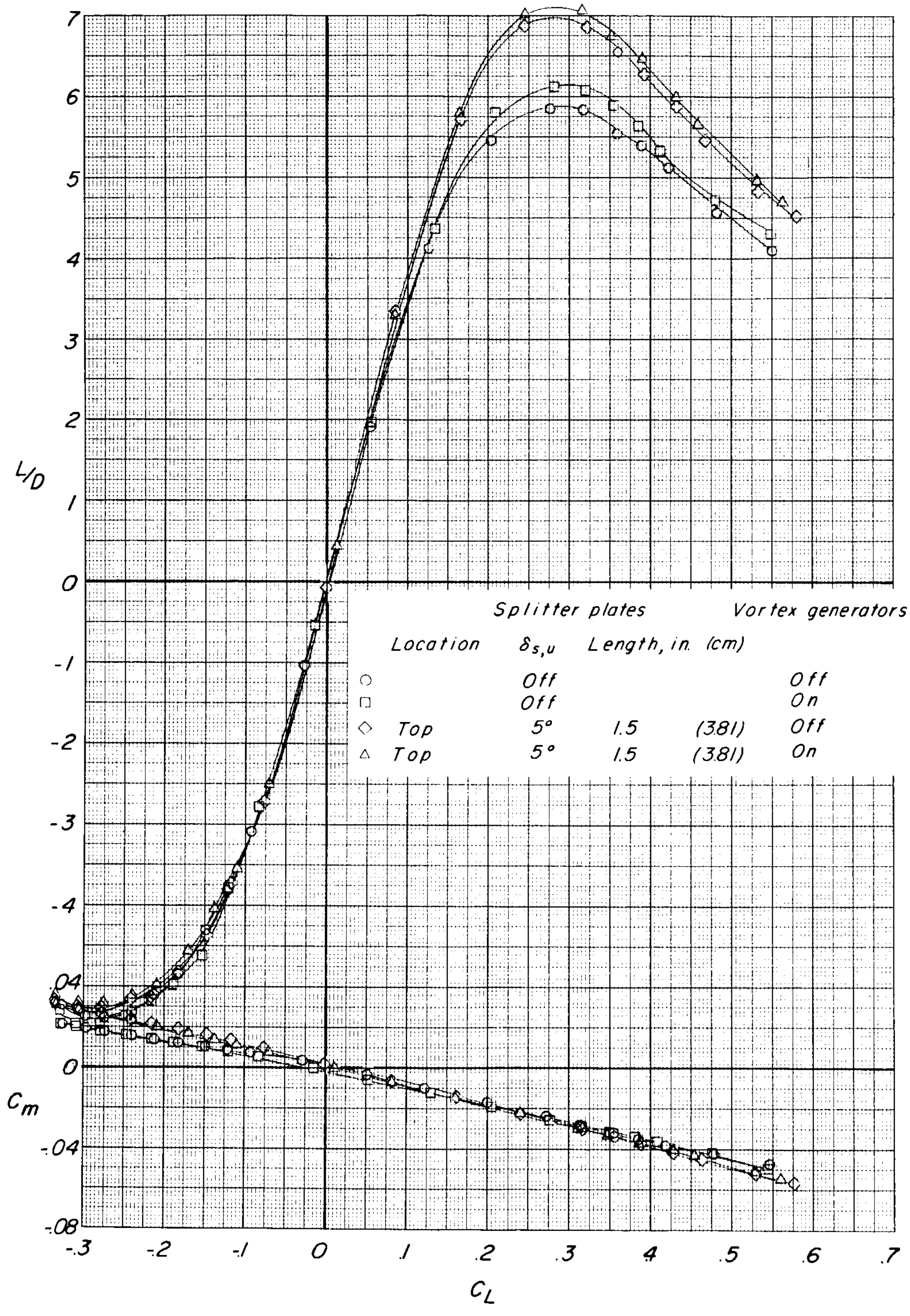


Figure 10.- Continued.



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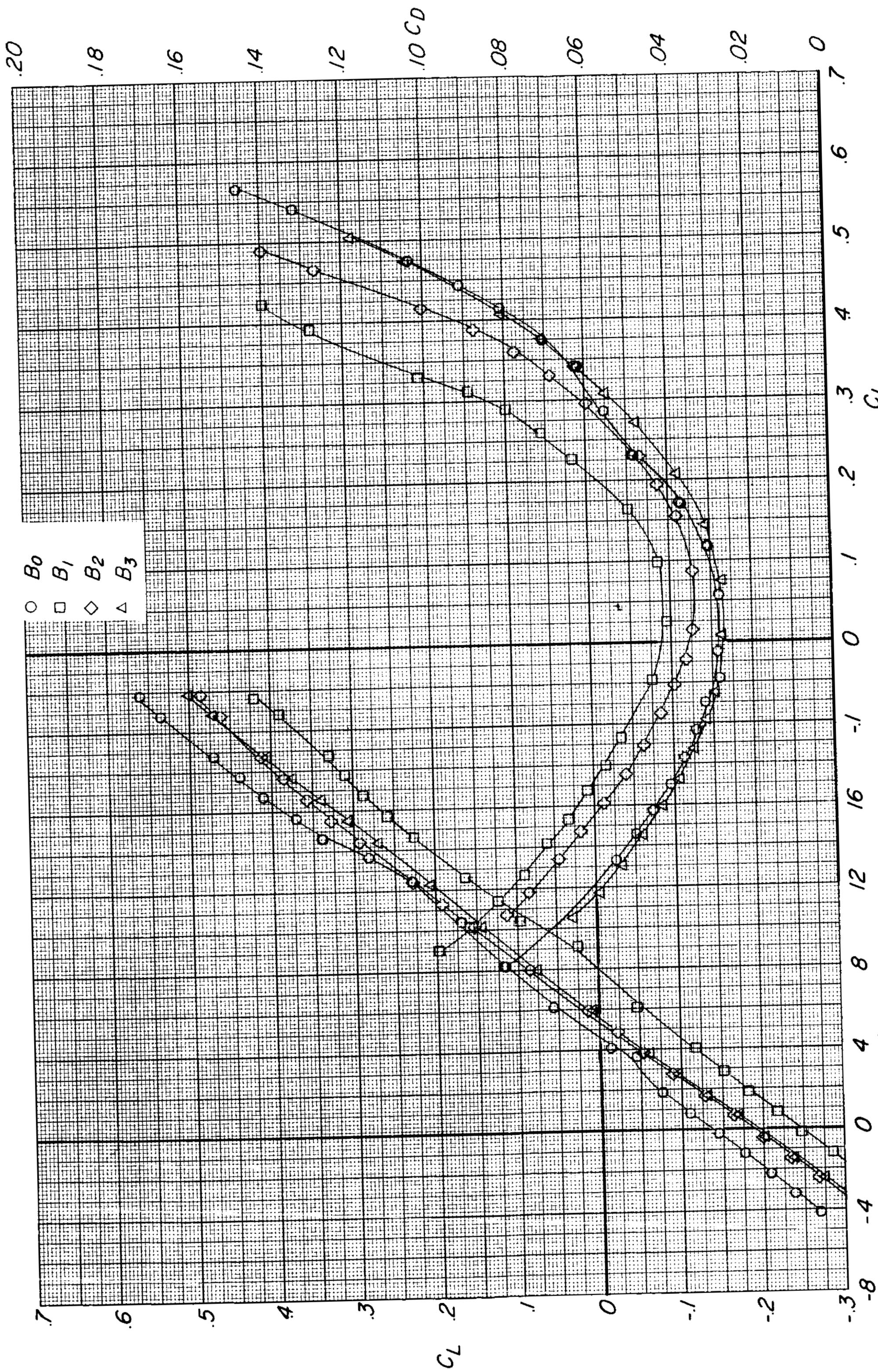

Figure 11.- Effects of changing body upper surface contour. Configuration $V_i 2V_0 0'$. Hinge line for $V_0 0'$ at 25 percent chord.

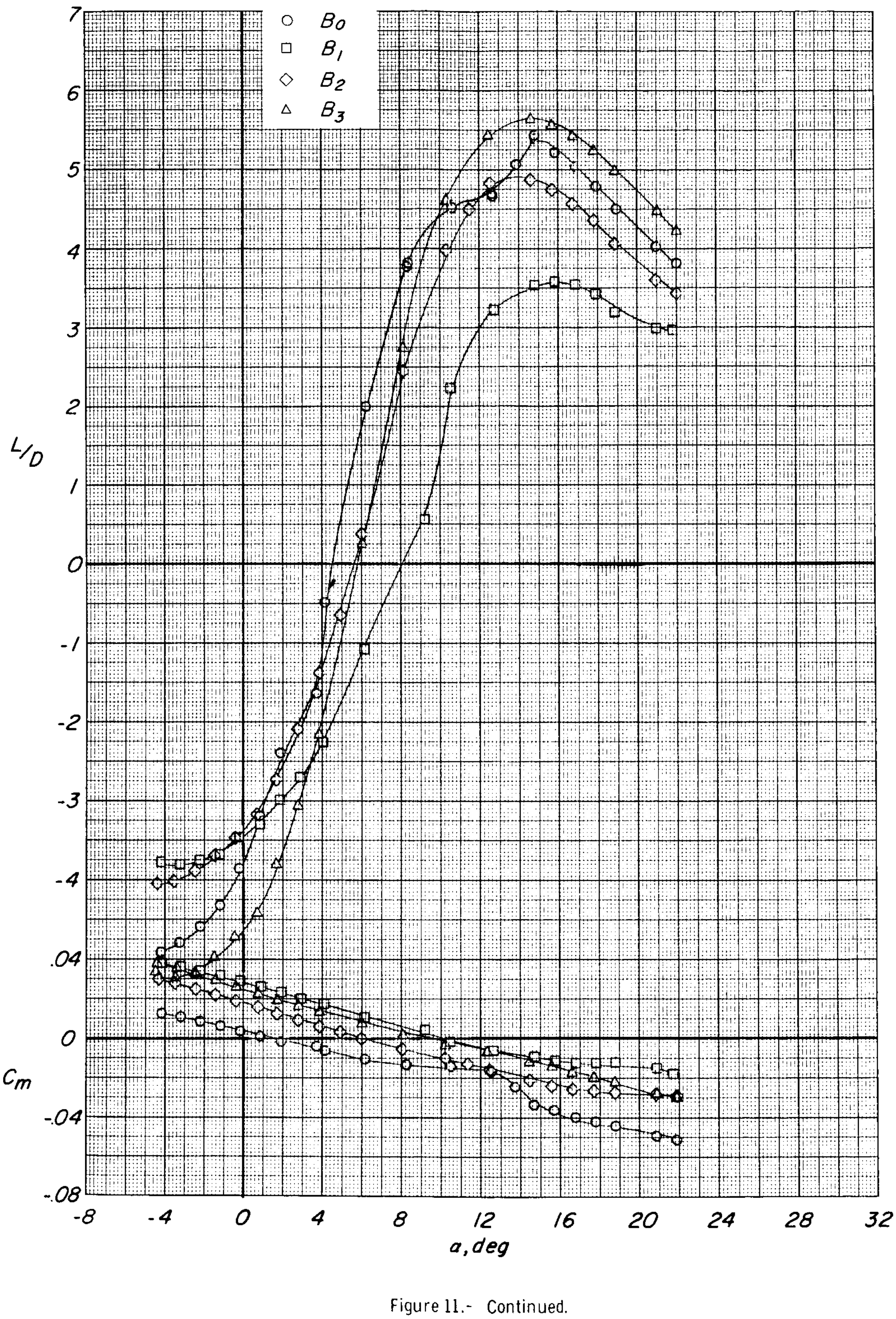

Figure 11.- Continued.

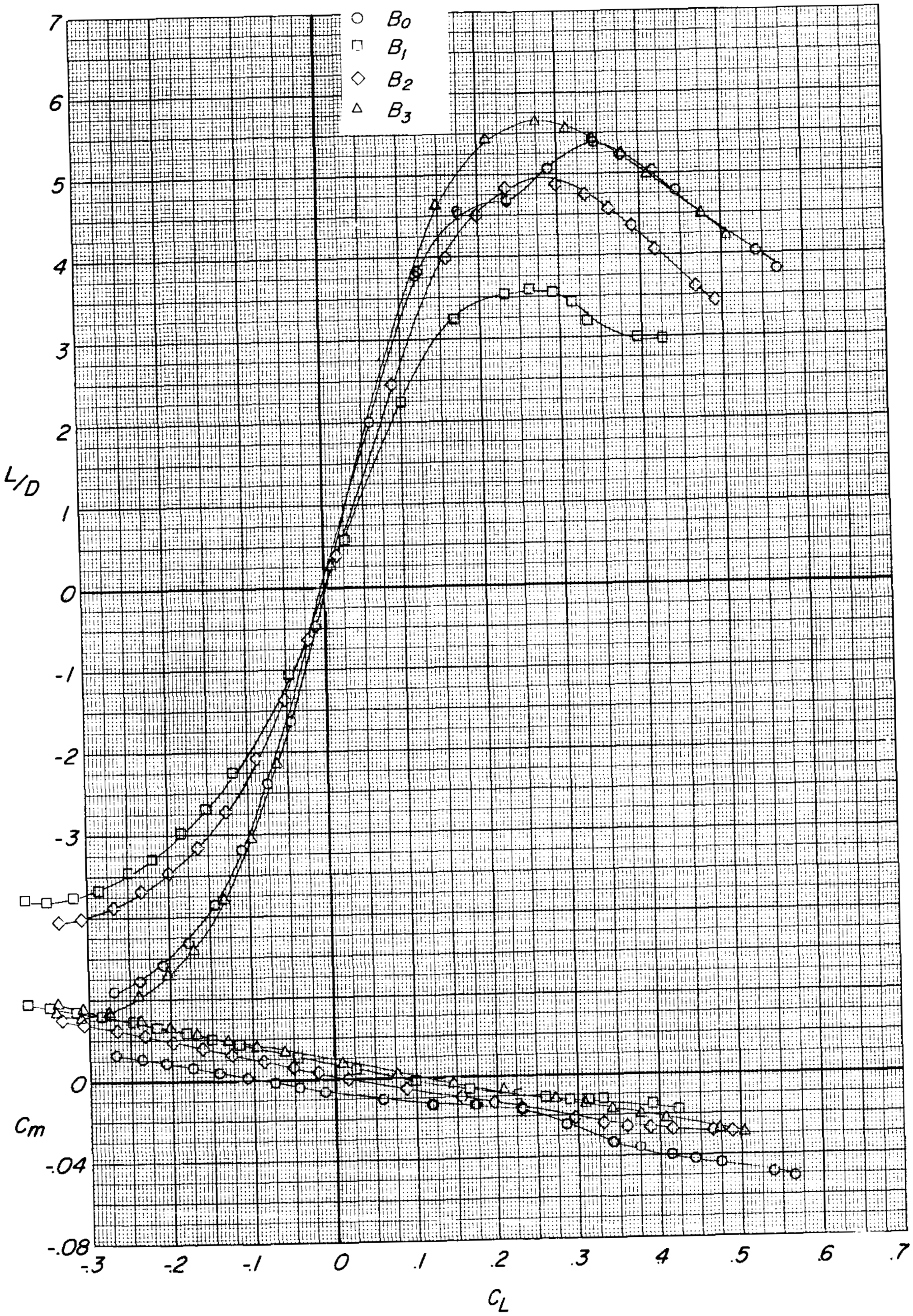

Figure 11.- Concluded.

[redacted]

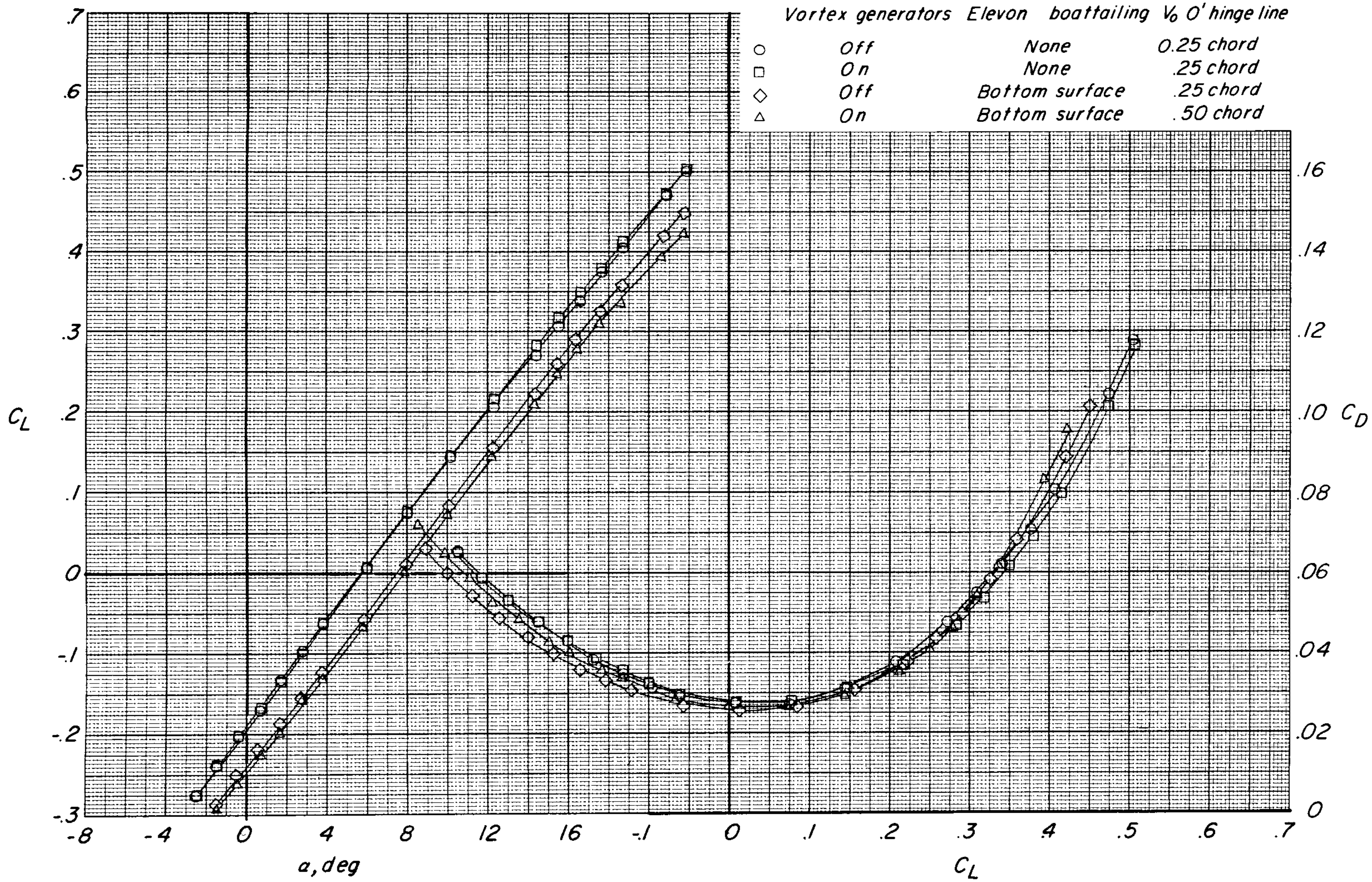

Figure 12.- Effects of various combinations of body-base changes and outboard-tail rudder-hinge-line locations, with and without vortex generators. Configuration $B_3V_i2V_o0'$.

[redacted]

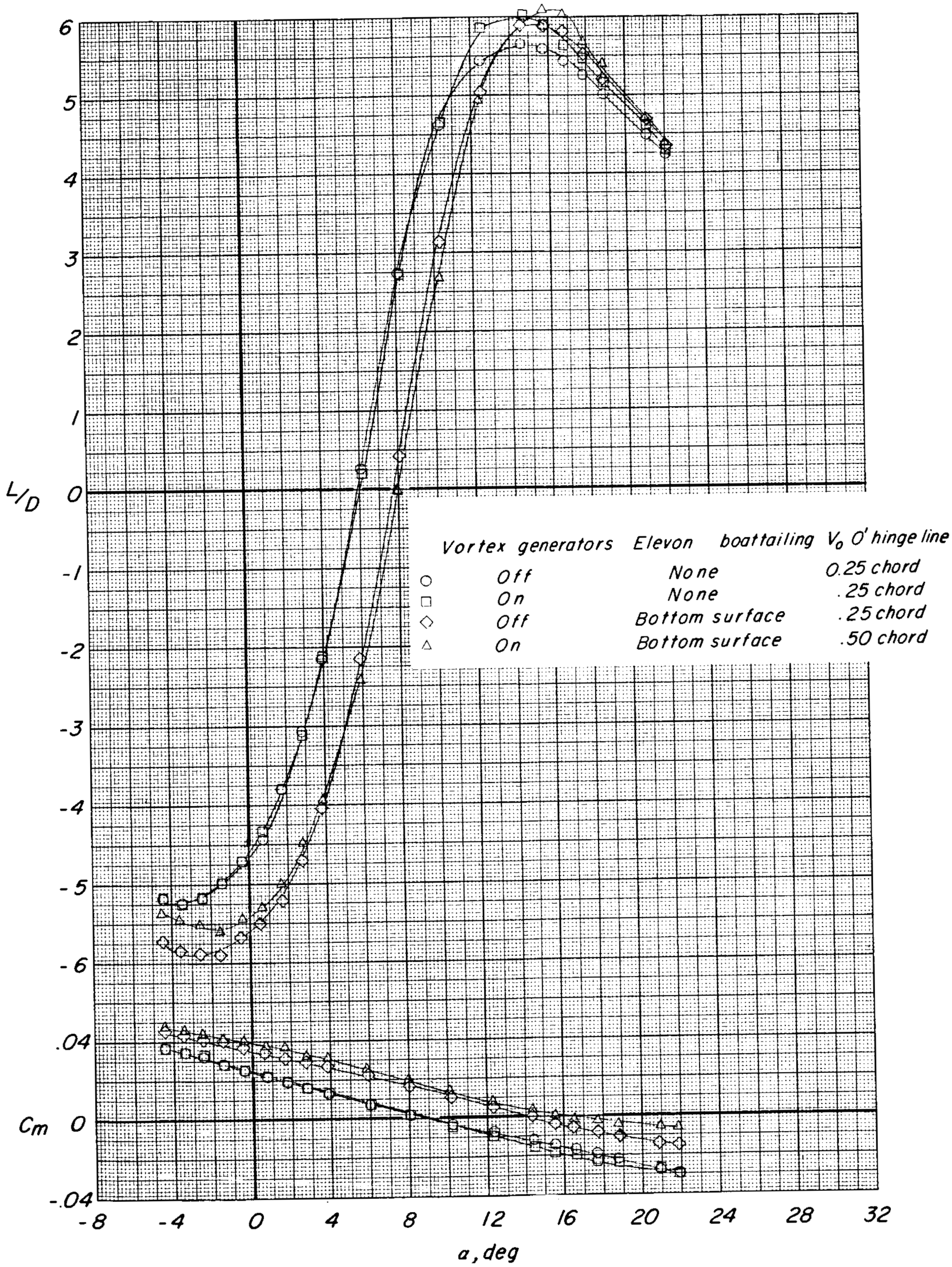

Figure 12.- Continued.

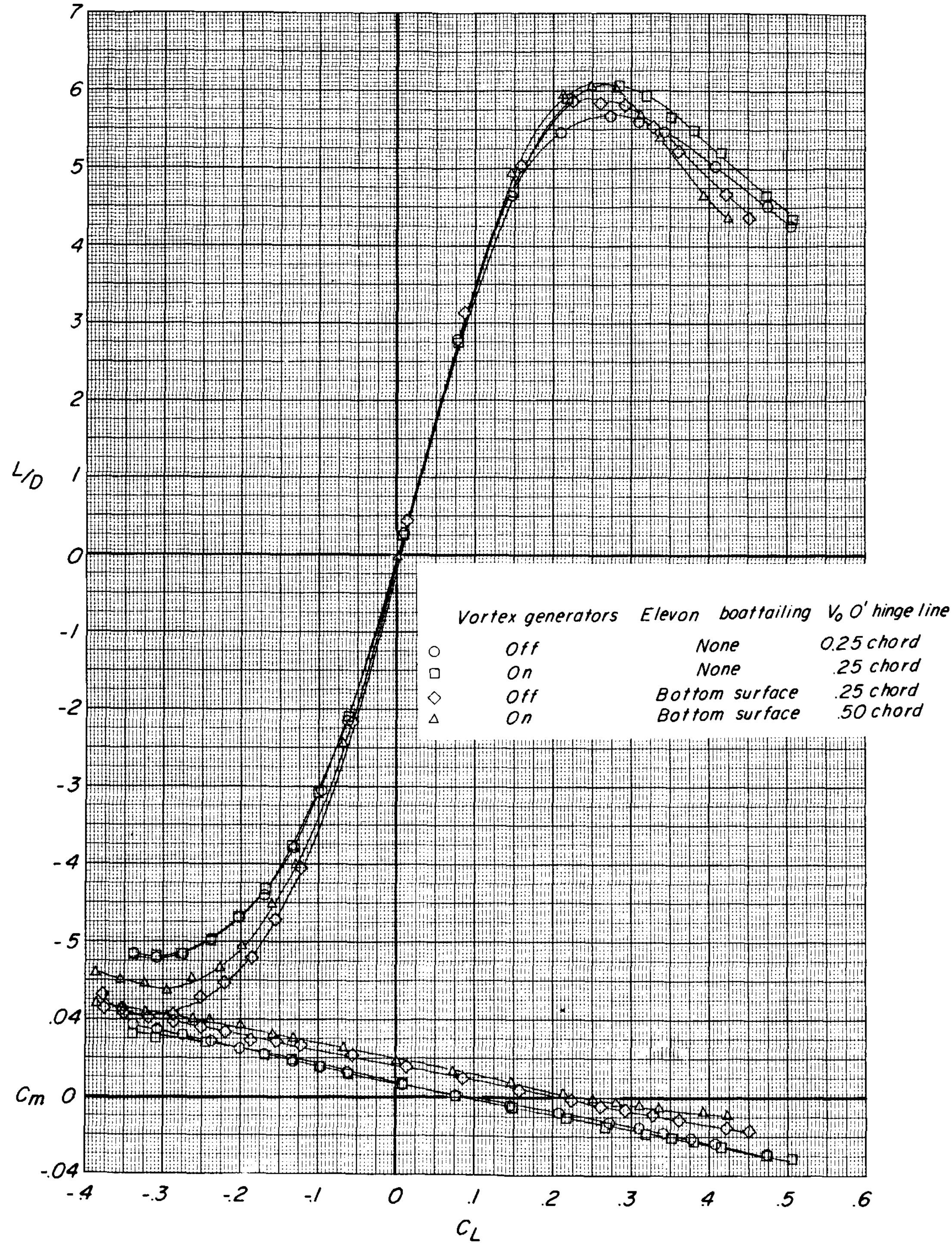

Figure 12.- Concluded.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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